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SUMMARY TECHNICAL REPORT ON

TRANSIENT PRESSURE MEASURING METHODS RESEARCH

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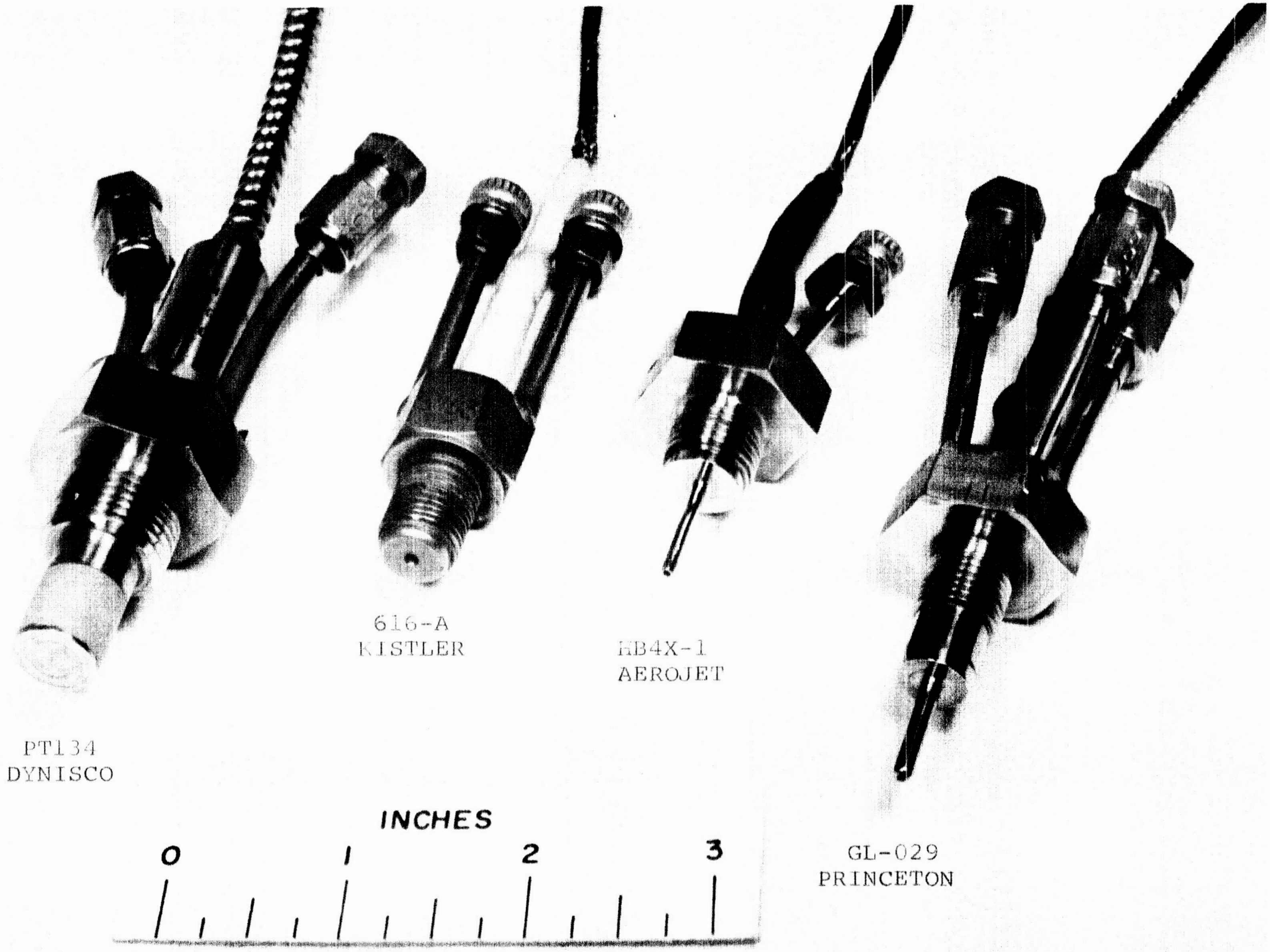
FRONTISPIECE



Advanced Transducers for Transient Pressure Measurements
in Liquid Propellant Rocket Thrust Chambers

CONTENTS

FIGURES

I. SUMMARY

During this terminal period of research in Transient Pressure Measuring Methods, transducer evaluations in the laboratory and in test rocket motors continued primarily on noncooled transducers in cooled adaptors and on variations of the Princeton Small Passage Technique.

Late model Dynisco PT49CF transducers, that were evaluated during the previous research period, are discussed herein since their most recent modification had a direct bearing on the development of the Dynisco model PT134 transducers. Redesign and further development of the model PT134 transducers by the manufacturer during most of this research period prevented the intensive testing needed to fully evaluate this advanced water cooled, flush diaphragm transducer.

Several models of cooled adaptors, on consignment for evaluation from the Kistler Instrument Company, were recalled by the manufacturer because of obsolescence before laboratory evaluations were completed. These were replaced by new and improved models late in the period.

A study of the dynamic response of small passage connected transducers, as affected by passage length and volume geometry, was continued. Work also continued on the digital computer analysis of the dynamic response of pressure transducers to shock inputs. In addition, a special study was made of the accuracy of heat transfer measurements with water cooled, flush diaphragm pressure transducers. Attention was given to transducer mounting and installation problems, especially gaskets and sealing.

Rocket motor testing and work on improving equipment for the evaluation of transducers in the laboratory was curtailed towards the end of the period in favor of completing as many of the laboratory evaluations as possible prior to shipment of the laboratory equipment to Battelle Memorial Institute where the evaluation will be continued. Rocket motor tests will be conducted beyond this research period.

II. TRANSIENT PRESSURE TRANSDUCER EVALUATIONS

The pace at which transducers were evaluated was set by the availability of transducers and the time required to provide satisfactory hardware for installing the instruments in the laboratory equipment and the rocket motors. Over twenty pressure transducers and transient pressure measuring systems were started through the evaluation procedure in the course of this research period. Selected preliminary evaluations of those instruments on which laboratory testing was completed are included in this report as Appendix A.

A. Water Cooled Flush Diaphragm Transducers

Three models of this type transducer available for evaluation were the Dynisco Models PT49 and PT134 and the Elastronics Model EBL 6009N/P.

1. Laboratory Evaluation

a. Dynisco PT49CF

Two model PT49CF-2M transducers of the latest design (Serial Nos. 21148 and 21208) were evaluated for the NASA Marshall Space Flight Center. Design features, important in the development of the model PT134 transducers, were studied including evaluation of the coolant passage design, especially in the diaphragm area, the thoria-dispersed nickel diaphragm, and the method of attaching the diaphragm to the transducer body.

A new and more rugged transducer body was also incorporated in this design to help overcome the sealing problem. Maximum allowable torque on previous models of the flange mounted PT49 transducers did not provide sufficient gasket loading for proper sealing. A plot of transducer output vs applied torque on retaining screws is found in the evaluation of transducer Serial No. 21208 in Appendix A. Maximum allowable torque on stainless steel screws with bearing washers but without lubrication was set at 30 inch pounds since the plot suggests that this amount of torque carried the transducer body to the stress-strain proportional limit and further loading may cause a yield to column action between the gasket flat and the retaining flange.

Zero drift, zero shift due to coolant pressure, and hysteresis were negligible with excellent linearity displayed in the static pressure calibrations of both transducers. Coolant flowrate and average coolant pressure were increased 25 percent and 40 percent respectively above rated conditions established for the previous PT49AF models.

A resonant frequency of approximately 25,000 cps was determined in the shock tube and although some irregularities did appear in the amplitude ratio vs frequency data, both transducers exhibited a flat (± 10%) response to 10,000 cps in the Sinusoidal Pressure Generator.

A coolant temperature rise of 3.2°F per Btu sec^{-1} in^{-2} of heat flux was recorded at low heat flux values (1.5 to 3) in the laboratory, indicating an expected 80°F coolant temperature rise at the 25 Btu sec^{-1} in^{-2} heat flux level.

b. Dynisco PT134

The research period started with four prototype instruments available for evaluation. All PT134 transducers were evaluated at an average coolant pressure of 225 lb in^{-2} gage and a coolant flow of 0.080 lb sec^{-1}. Coolant in all cases was distilled water supplied from a closed system pressurized with nitrogen gas. Coolant pressure rating was established by comparing flow data collected at various pressure levels and selecting the average coolant pressure for which the coolant pressure drop vs coolant flow curve did not shift more than 5 percent when average coolant pressure was increased 50 lb in^{-2} gage. Example; for the same coolant pressure drop, the coolant flow curves of Figure 1 show a decrease in flow of 11.5 percent at an average pressure of 275 lb in^{-2} gage from that established at 225 psig and the selected flow rate of 0.08 lb sec^{-1}. Maximum rated coolant flow was established at a value considered to be safely below the flow cavitation level at rated average coolant pressure. Four of the six samples available to date exhibited these same coolant flow characteristics.

Coolant Pressure Drop vs Coolant Flow

Dynisco PT134-1.5M

Serial No. 22123

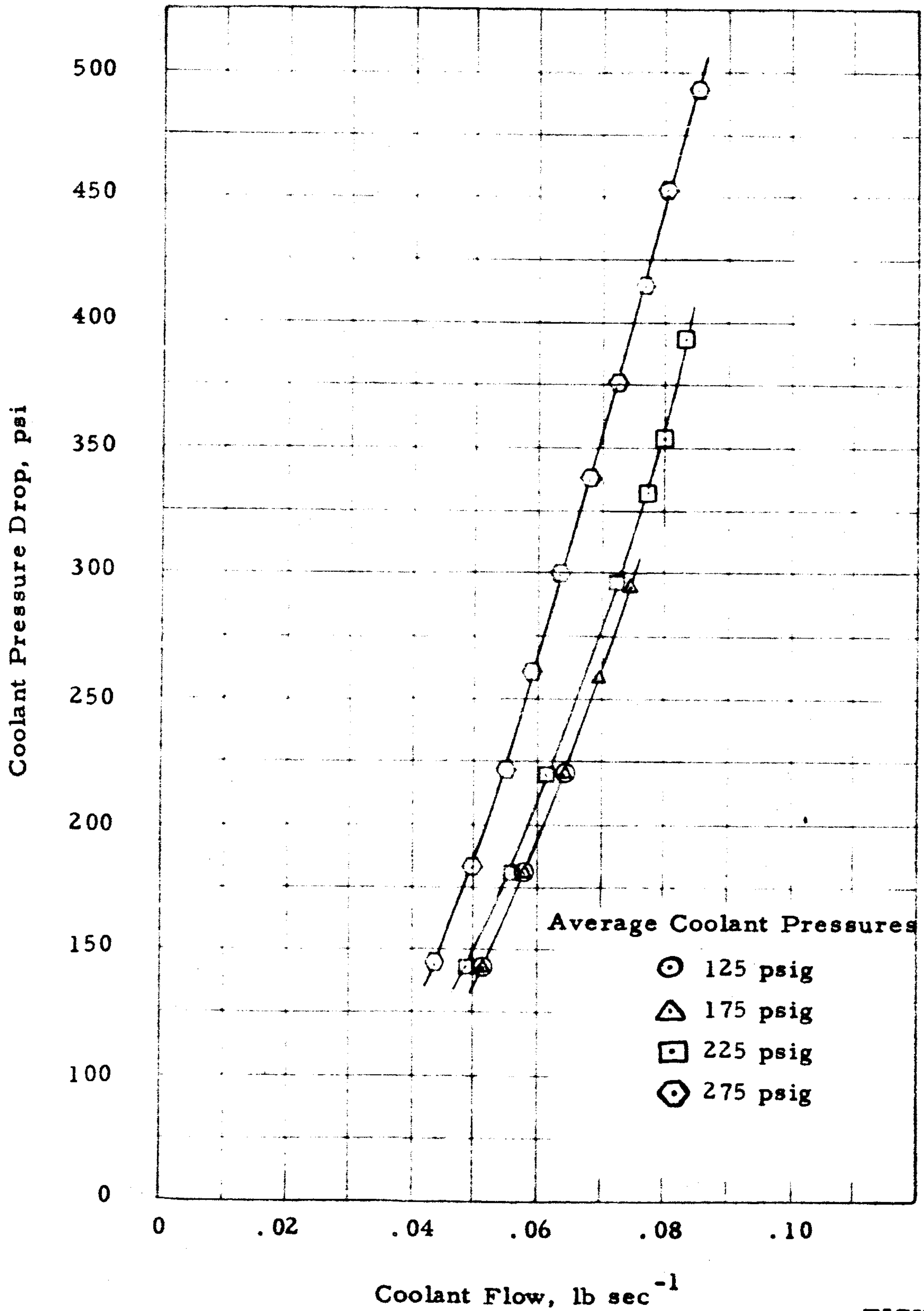


FIGURE 1

During a previous coolant flow and pressure test, in which an earlier prototype PT134 was tested to destruction, physical measurements of the external transducer dimensions showed no growth or movement of transducer body or diaphragm up to 2200 lb in^{-2} gage. Failure occurred when the inner coolant shell collapsed under pressure at approximately 2225 lb in^{-2} gage. A conclusion to be drawn from Figure 1 then is that some internal structural movement is contributing to the coolant pressure drop across the transducer as the average coolant pressure is raised.

Figure 2 is a display of coolant flow data at rated average coolant pressure for several prototype PT134 transducers. The spread of data is apparently a result of variations in the manufacturing process and currently is considered to be of little consequence since no effect on transducer performance was detected in the measurement of either steady state or transient pressures. Coolant flow calibrations at 1000 lb in^{-2} gage and 1200 lb in^{-2} gage average coolant pressure and the effect of pressure applied to the diaphragm on coolant flow are shown in Figure 3. The zero output shift of this transducer, caused by 1200 lb in^{-2} gage average coolant pressure, amounted to 11 percent of full scale output as seen in the static pressure calibrations of Figure 4.

Static pressure calibrations of the PT134 transducers, with and without coolant flow, disclosed very good linearity and little hysteresis. The average deviation in output from a computed best fit straight line did not exceed 0.25 percent of full scale output even when calibrations were extended to 1-1/2 times full scale.

Dynamic testing in the shock tube indicated resonant frequencies ranging from 35,000 to 40,000 cycles per second. A flat response (± 10%) up to 10,000 cycles per second was obtained in the Sinusoidal Pressure Generator.

Coolant Pressure Drop vs Coolant Flow

for Several Dynisco PT134 Transducers

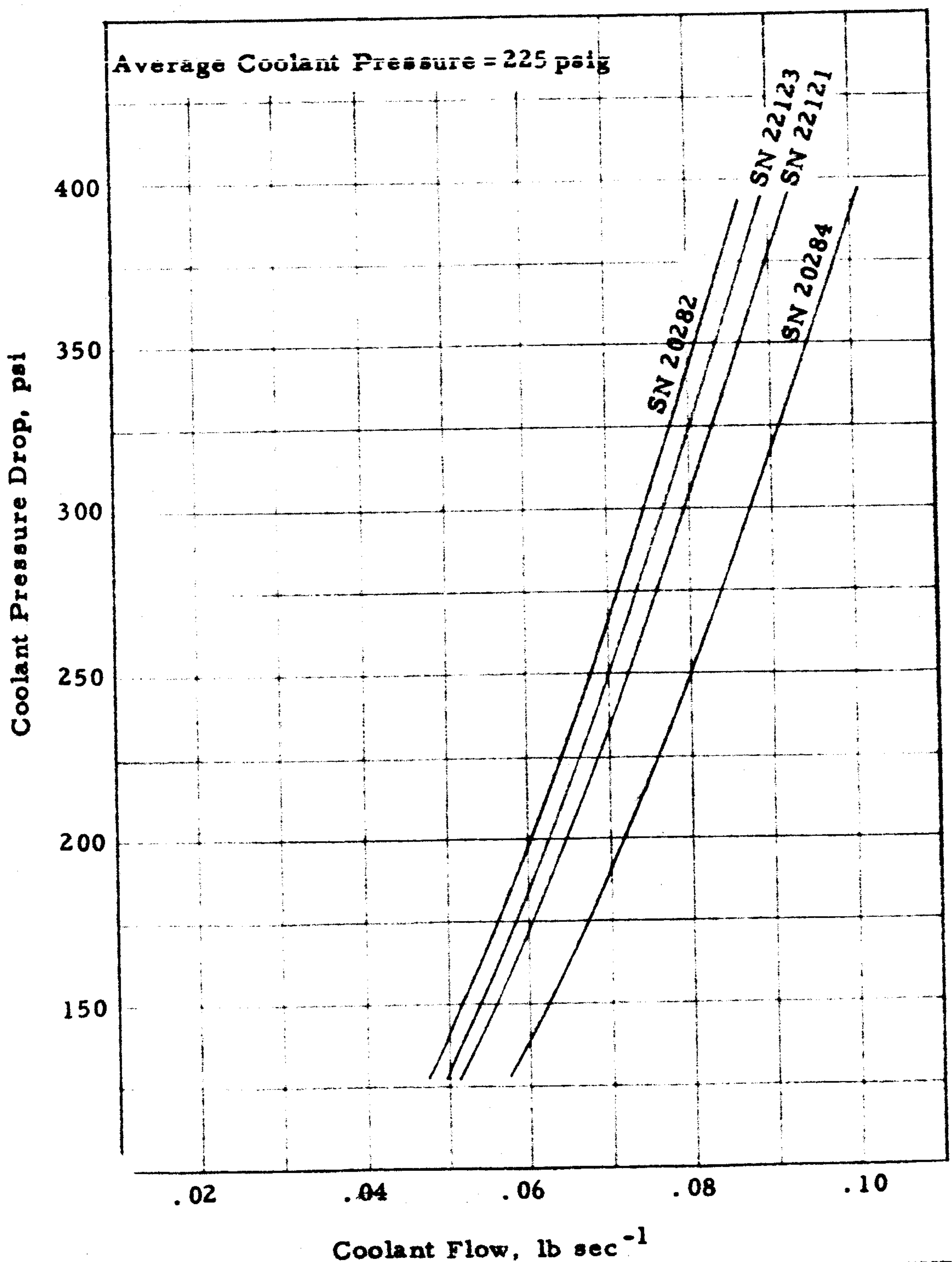


FIGURE 2

Coolant Pressure Drop vs Coolant Flow

Dynisco PT134-1M

Serial No. 20282

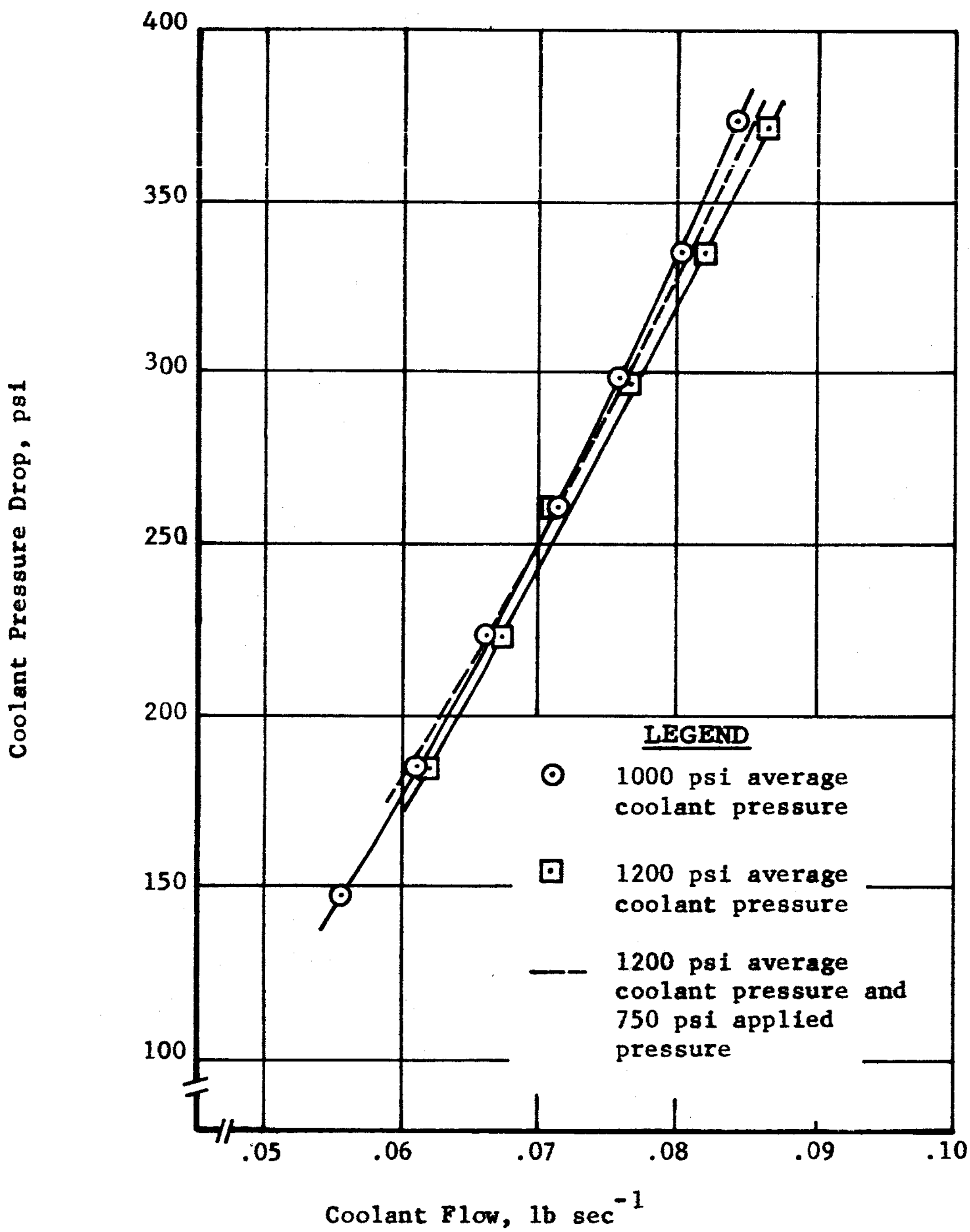
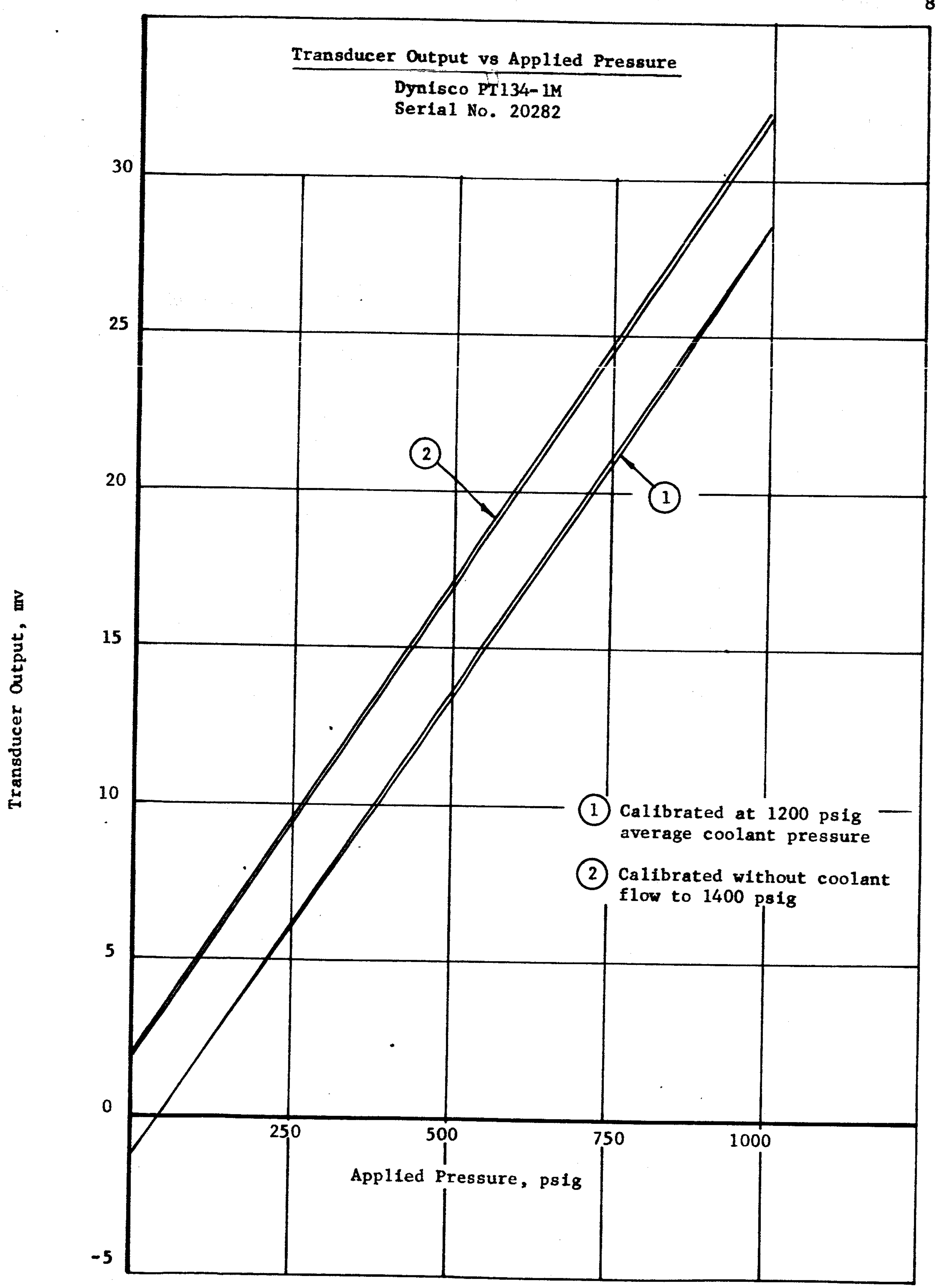


FIGURE 3


Transducer Output vs Applied Pressure
Dynisco PT134-1M
Serial No. 20282
30
25
20
15
10
5
0
-5
Transducer Output, mv
250
500
750
1000
Applied Pressure, psig
2
1
1 Calibrated at 1200 psig average coolant pressure
2 Calibrated without coolant flow to 1400 psig

c. Elastronics Model EBL 6009 N/P

Previous work with this transducer, especially static testing, was plagued by an exceedingly high drift rate. This problem was finally alleviated by the addition of new cabling, cleaning and sealing connections, and making charge amplifier adjustments. However, one of two units procured for evaluation, failed electrically from internal coolant leakage while trying to established rated coolant conditions; the second unit failed electrically during static pressure calibrations with coolant flow. Attempts to recover these instruments by cleaning and vacuum oven drying failed and they were abandoned.

2. Rocket Motor Tests

a. Dynisco Model PT49CF

Burnout occurred on transducer Serial No. 21148 at the diaphragm to transducer body joint and at the 12 Btu sec^{-1} in^{-2} heat flux level. Transducer body material burned away during testing in the transverse motor under conditions of combustion instability in the first tangential mode. Since heat fluxes at the same level were recorded for several rocket runs during longitudinal instability tests, burnout was attributed to transducer body wall thickness in a critical area. Transducer Serial No. 21208 suffered the same type of damage, but not as extensive. A modification was made in which one half of the wall material was removed and replaced with a press-fit copper sleeve. Tests were then made under similar conditions at the 14 Btu sec^{-1} in^{-2} heat flux level without injury to the transducer. This transducer later succumbed to electrical failure. However, sufficient information was gathered from the evaluations to assist in the selection of coolant passage design, diaphragm material, and method of construction for the PT134 transducers. The Dynisco model PT49C transducer became obsolete during this period and attention in the future will be directed toward the Model PT134.

b. Dynisco Model PT134

The Dynisco Model PT134 was the only advanced water cooled, flush diaphragm transducer available for rocket motor tests during this period. When coolant tube leaks and electrical failures occurred simultaneously on the first two instruments tested, they were returned to the manufacturer for repair and further modification. The hexagonal section of the transducer was enlarged to 1.30 inches (across the points) to permit the use of larger coolant tubes and allow for a more sturdy construction. Electrical failures were attributed to coolant entering the upper transducer section when coolant tube leaks developed. Signal leads were armored and sealed connectors installed. This later version of the PT134 appears in the FRONTISPIECE. In addition to the above modifications, considerable time and effort was given by the manufacturer to the problem of reducing heat transfer by ceramic-coating the cylindrical bodies of some transducers and the diaphragms of others. Rocket motor tests had previously indicated that a large amount of the heat picked up by the coolant was from along the sides of the cylindrical portion of the transducer bodies.

Heat flux to Dynisco Model PT134 transducers averaged 1.2 times that to a model PT49C monitor transducers in twenty rocket runs at values ranging from 6 to 12 Btu sec^{-1} in^{-2}. Tests were performed in which rocket motor conditions were repeated with the PT134 and monitor transducers alternately placed in the same location in the chamber wall. Tests in which monitor and test transducers were placed opposite each other in the chamber were also repeated with transducer positions exchanged. In all cases the PT134 indicated a higher specific heat flux than the monitor transducer. Steady state and transient pressure data was excellent during all rocket motor testing. The redesigned PT134 transducers were not forwarded in time for evaluation before the end of this reporting period. It is hoped that significant rocket motor test results can be presented in the final report.

B. The Princeton Small Passage Technique

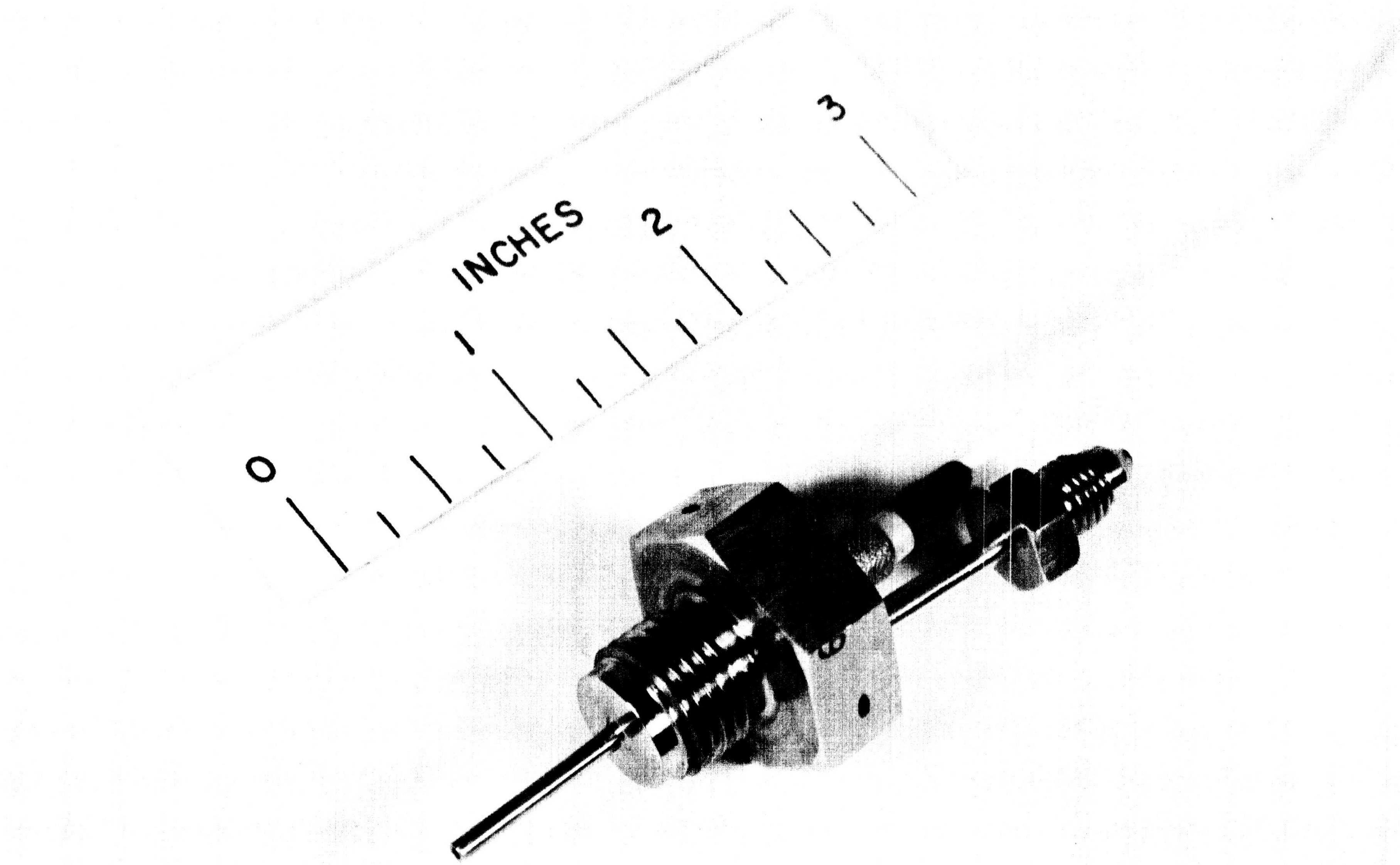
Several versions of this technique, both cooled and uncooled, with different external dimensions appeared on the scene during this research period. All gave excellent performance in the laboratory within their limitations and rocket motor tests yielded quite favorable results.

1. Laboratory Evaluations

a. Aerojet-General Model HB3X-1 Adaptor

The HB3X-1 adaptor, shown in Figure 5, houses a Kistler 601A miniature quartz transducer and helium bleed designed according to this technique. The choked flow conditions, required of the helium bleed system for satisfactory dynamic performance and passage cooling, are controlled by a small jewel orifice. Repetetive orifice calibrations, shown in Figure 6, provided the required helium supply pressure settings throughout the evaluation. A plot of the static calibration is found in Figure 7 and shows the typically linear output of the Kistler 601A transducer.

Meaningful results could not be obtained from the shock tube due to anomalous thermodynamic effects in the small passage. Figure 8 shows the dynamic response in the Sinusoidal Pressure Generator with and without the dynamic compensation offered by an L-R-C filter. The filter characteristic is also shown in Figure 8 and a schematic of the circuit is found in Figure 9. Amplitude response is seen to be flat (± 10%) to 8000 cps when dynamically compensated and effects on phase lag are still being evaluated. The amplitude data always repeated and the irregularity in the response curve at about 6000 cps is attributed to the method of introducing helium into the small passage. In a study of the effects of passage length and geometry on the dynamic response of small passage connected transducers, which is discussed below, the HB3X-1 configuration was duplicated except for the internal design for the helium bleed. Response as determined from SPG data showed no irregularities nor did photographed displays on a Panoramic sonic analyzer at any test frequency.



AEROJET-GENERAL CORPORATION GEMSIP SMALL PASSAGE TECHNIQUE
PRESSURE TRANSDUCER ADAPTOR-MODEL HB 3X-1 S/N 002

Figure 5

Helium Supply Pressure vs. Bleed Flow

AGC GEMSIP ADAPTOR HB3X-1 SERIAL 002

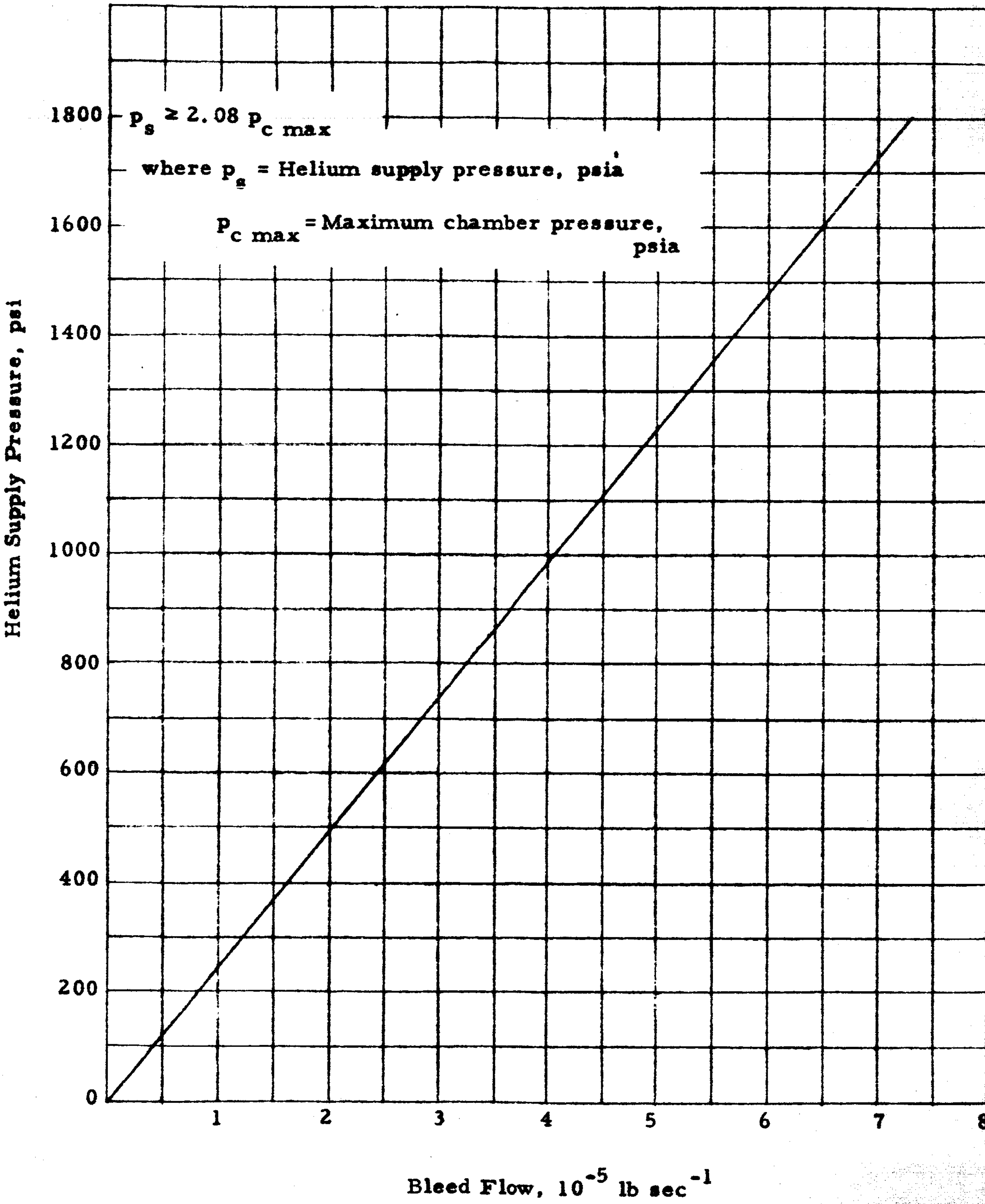


FIGURE 6

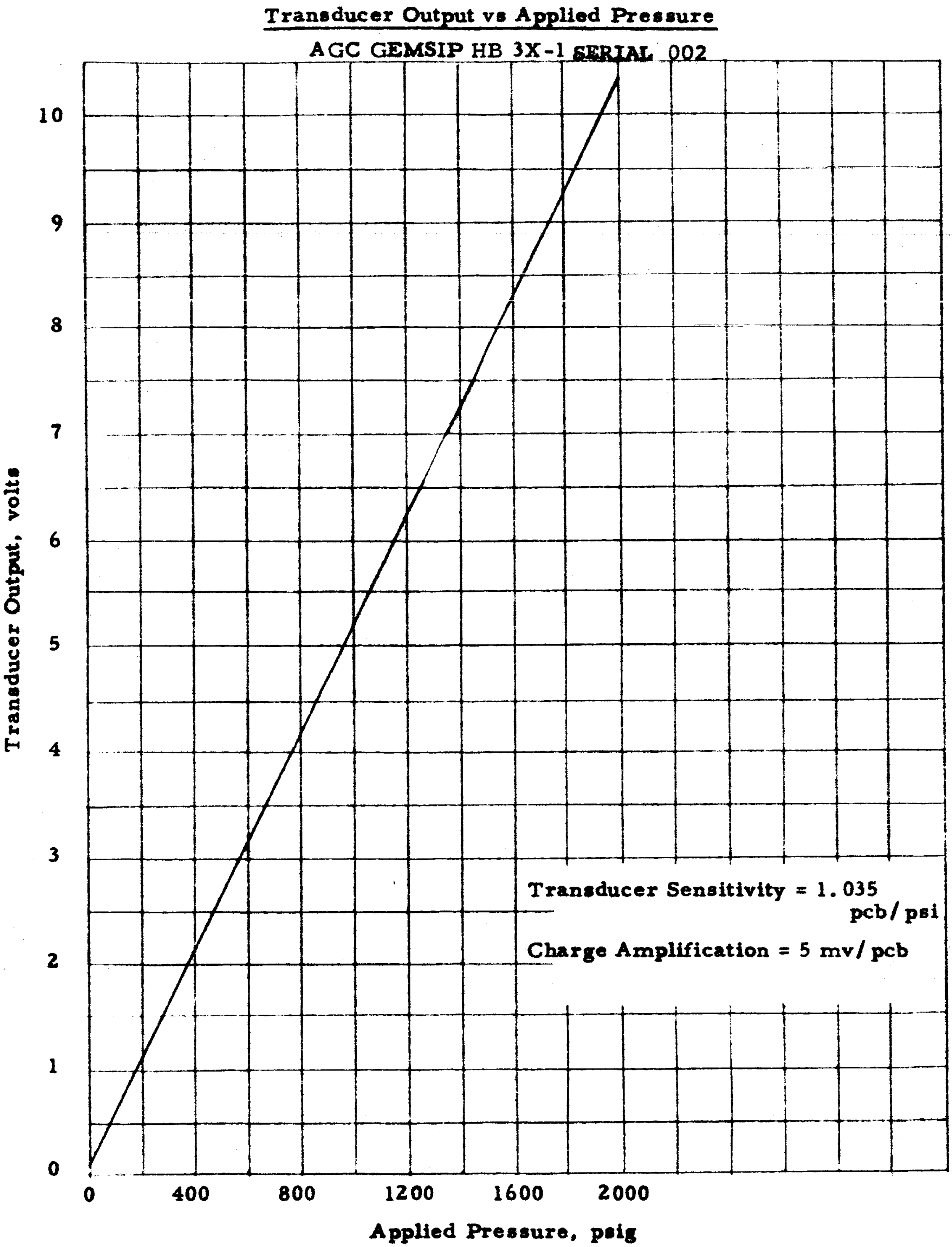

Transducer Output vs Applied Pressure
AGC GEMSIP HB 3X-1 SERIAL 002
Transducer Output, volts
0
1
2
3
4
5
6
7
8
9
10
0
400
800
1200
1600
2000
Applied Pressure, psig
Transducer Sensitivity = 1.035 pcb/psi
Charge Amplification = 5 mv/pcb

FIGURE 7

Amplitude Ratio vs. Frequency

Aerojet GEMSIP HB3X-1

LEGEND

1 HB3X-1 Dynamic Test
2 Dynamic Compensation Filter
3 HB3X-1 Dynamically Compensated Test

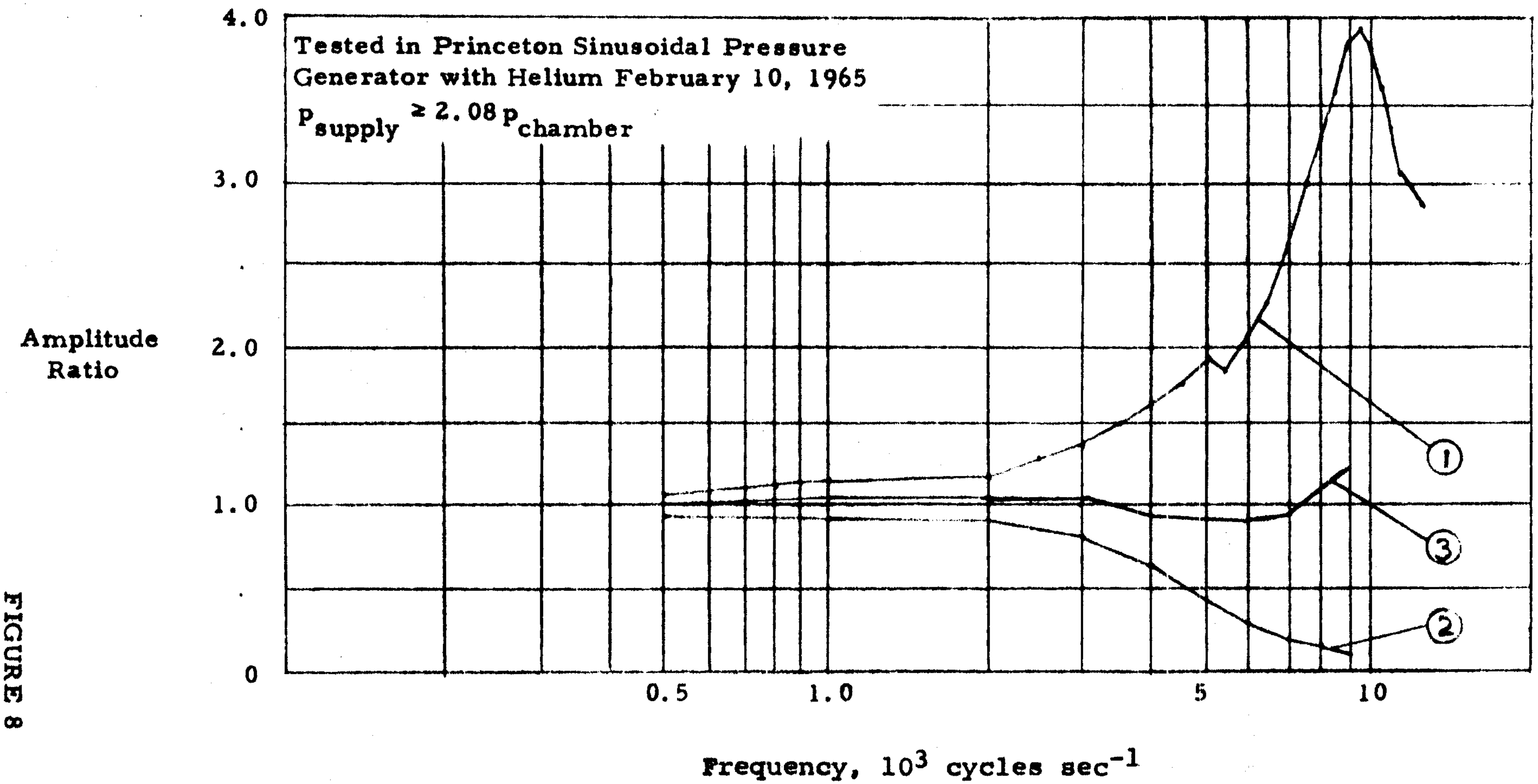
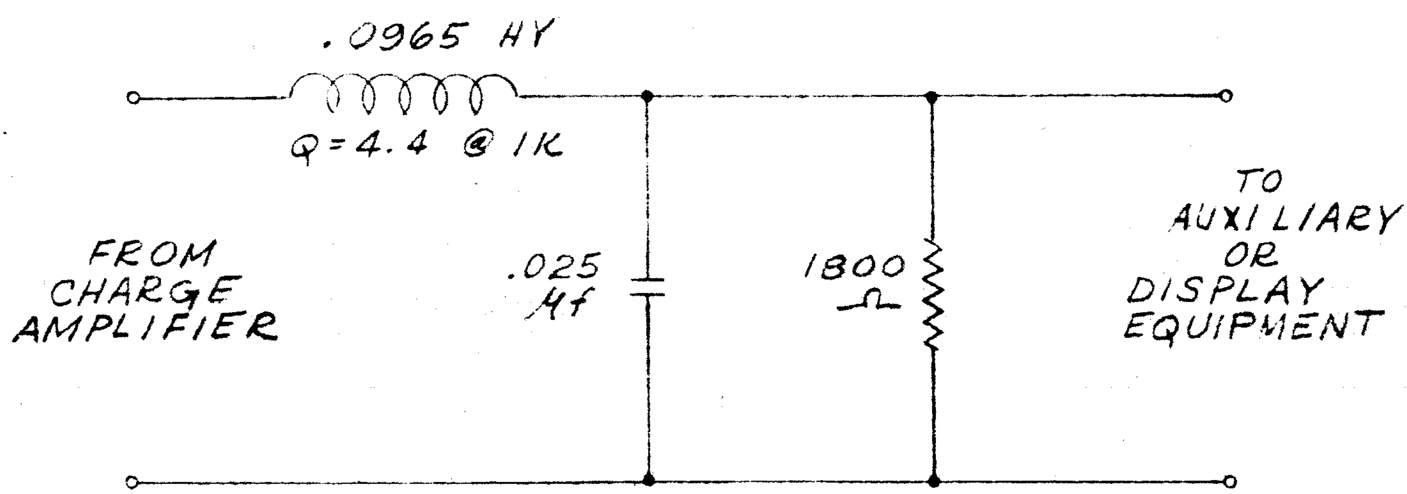


FIGURE 8



SCALE:	TOLERANCES UNLESS NOTED	NO.	CHANGE	BY	APP.
DATE: FEB. 23, 1965	(NON-ACCUMULATIVE)	NO. REQ'D:			
DESIGNED:	.XXX = ± .002"	MAT'L:			
DRAWN: A.C.J.	.XX = ± .005"	FINISH UNLESS NOTED: √			
CHECKED: R.W.C.	FRACTIONS = ± 1/32"	TITLE: DYNAMIC COMPENSATION FOR AGC HB3X-1			
APP'D:	ANGLES = ± 1°				

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DWG. NO. JP24 S2023 A

b. Aerojet-General Model HB4X-1 Adaptor

The HB4X-1 small passage adaptor is very similar to the Model HB3X-1. Outline dimensions are the same and the same model transducer is used. Passage diameter has been changed, decreasing in steps of several thousandths of an inch, and the helium bleed passages have been altered. Although the evaluation appears in Appendix A, the SPG curve is presented as Figure 10 for comparison with performance of the Model HB3X-1 adaptor. Time did not permit the construction and calibration of a dynamic compensating filter for this unit.

c. Kistler Model 616H

The 616H is a water cooled adaptor with an internal geometry made to accommodate a cooled protective thermal barrier for a Kistler 601A quartz transducer and a helium bleed. The slightly open curve and small zero shift seen in the static calibration of the evaluation in Appendix A was caused by an average zero output drift of 0.04 percent F.S. per minute.

Thermodynamic effects within the small passages have not permitted accurate analysis of response data from a shock input to date. However, the relatively large diameter and short length passage of the 616H should allow a close approximation of passage acoustic response. The resonant frequency of the short passage-protective barrier configuration with helium bleed is about 24,000 cycles per second. Amplitude ratio versus frequency, as determined from SPG data, is reasonably flat to 7000 cycles per second. It is not known at present whether output attenuation below 5000 cycles per second is caused by the relatively large volume at the end of the passage, the presence of the cooled protective barrier, or other effects.

d. Guggenheim Laboratories Model GL029 Cooled Probe Adaptor

Based on performance of the Guggenheim Laboratories GL017 Small Passage Technique Adaptor, in which a first resonant frequency of

Amplitude Ratio vs. Frequency

Aerojet GEMSIP HB4X-1

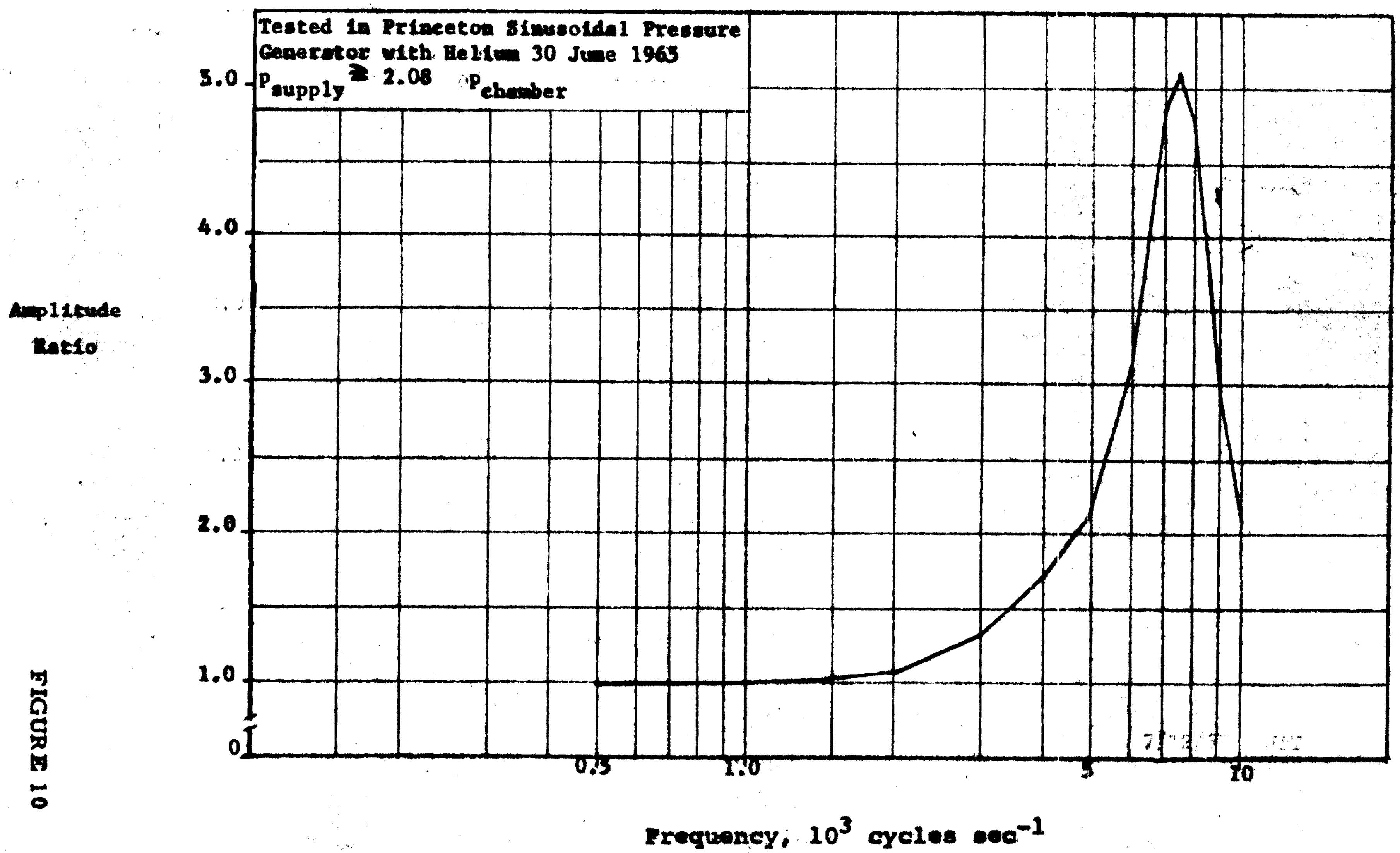


FIGURE 10

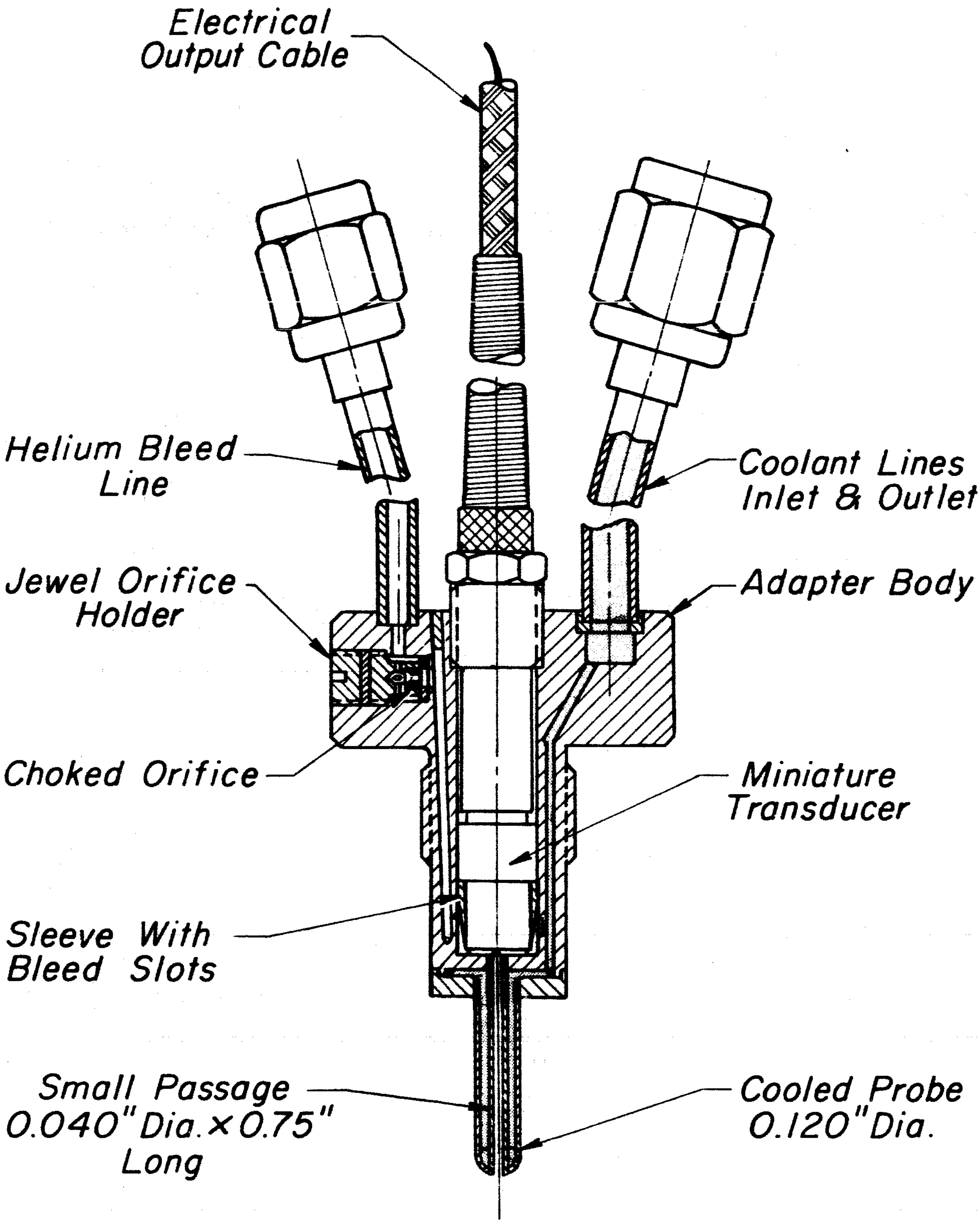
12,500 cycles per second and a flat response (± 10%) to 3000 cycles per second was realized, the GL029 cooled probe adaptor shown in the FRONTISPIECE was designed to be readily installed in a variety of research and development rocket thrust chambers. The unit was made at the Marshall Space Flight Center and arrived at Princeton late in the research period for evaluation. Although failure of the outer coolant shell prevented a full evaluation, sufficient data was accumulated to verify dynamic response comparable to the GL017 adaptor. Figure 11 shows the GL029 adaptor approximately double size and Figure 12 is the Amplitude ratio vs Frequency curve developed from SPG data. The unit was sectioned longitudinally to determine the cause of failure and for possible redesign information.

2. Rocket Motor Tests

All rocket motor run conditions were repeated as close as possible and transducers undergoing test were monitored by a Dynisco model PT49C transducer.

a. Aerojet-General Model HB3X-1 Adaptor

The rocket test data of Figure 13 shows a slight thermal drift which, during the course of several rocket motor firings, could not be reduced by increasing the helium bleed flow. The helium bleed provided adequate protection for the transducer diaphragm but, since neither rocket motor or the adaptor were cooled, enough heat evidently reached the transducer to cause the drift. Although the thermal drift rate is low, accurate steady state chamber pressure data can only be obtained when the device is used in a regeneratively cooled chamber or provision made for cooling such as in the GL029 adaptor. About 1/16 inch of the probe end burned away with no apparent effect on passage response. Transducer output was compensated with the L-R-C filter for this test although little difference is noticed in the Visicorder data between this and the uncompensated tests. The helium bleed tube failed during subsequent testing temporarily preventing further



GL029
Small Passage Technique Adapter

FIGURE 11

Amplitude Ratio vs Frequency

Guggenheim Laboratories GL029
Small Passage Technique Adaptor

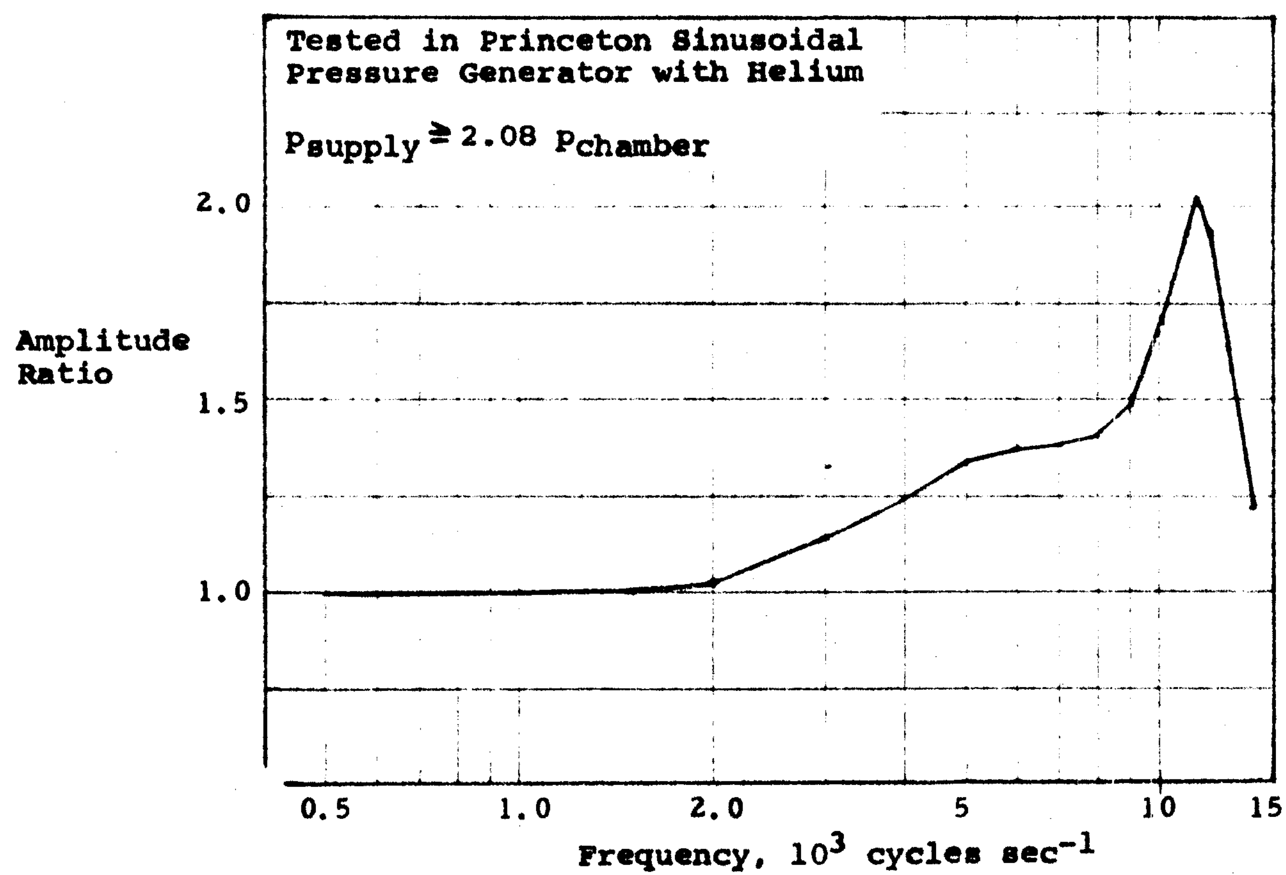
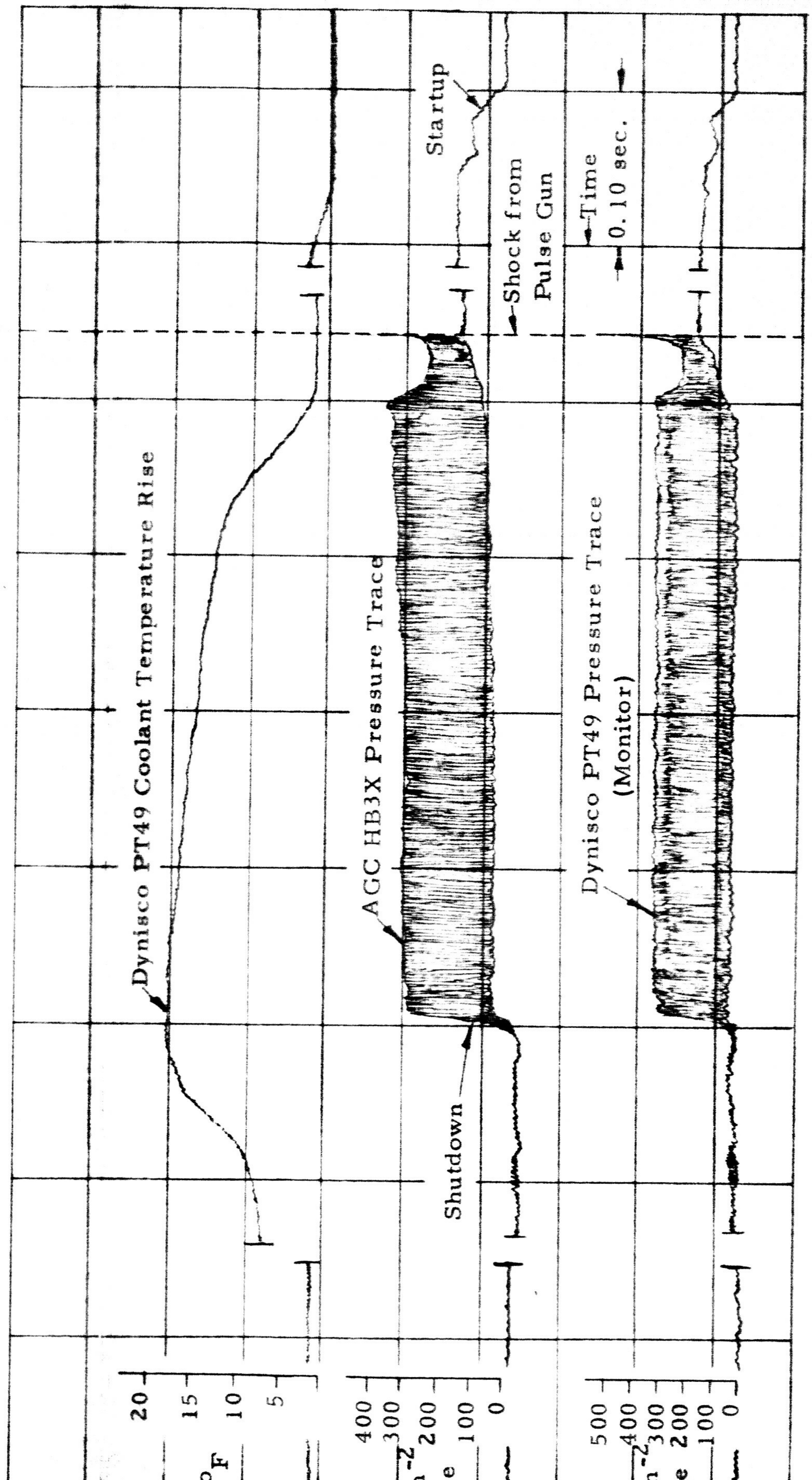


FIGURE 12



Oscillograph (Visicorder) Traces of AGC HB3X (#002) vs Dynisco PT49CF-2M (#21208) for Rocket Motor Test No. A1856

FIGURE 13

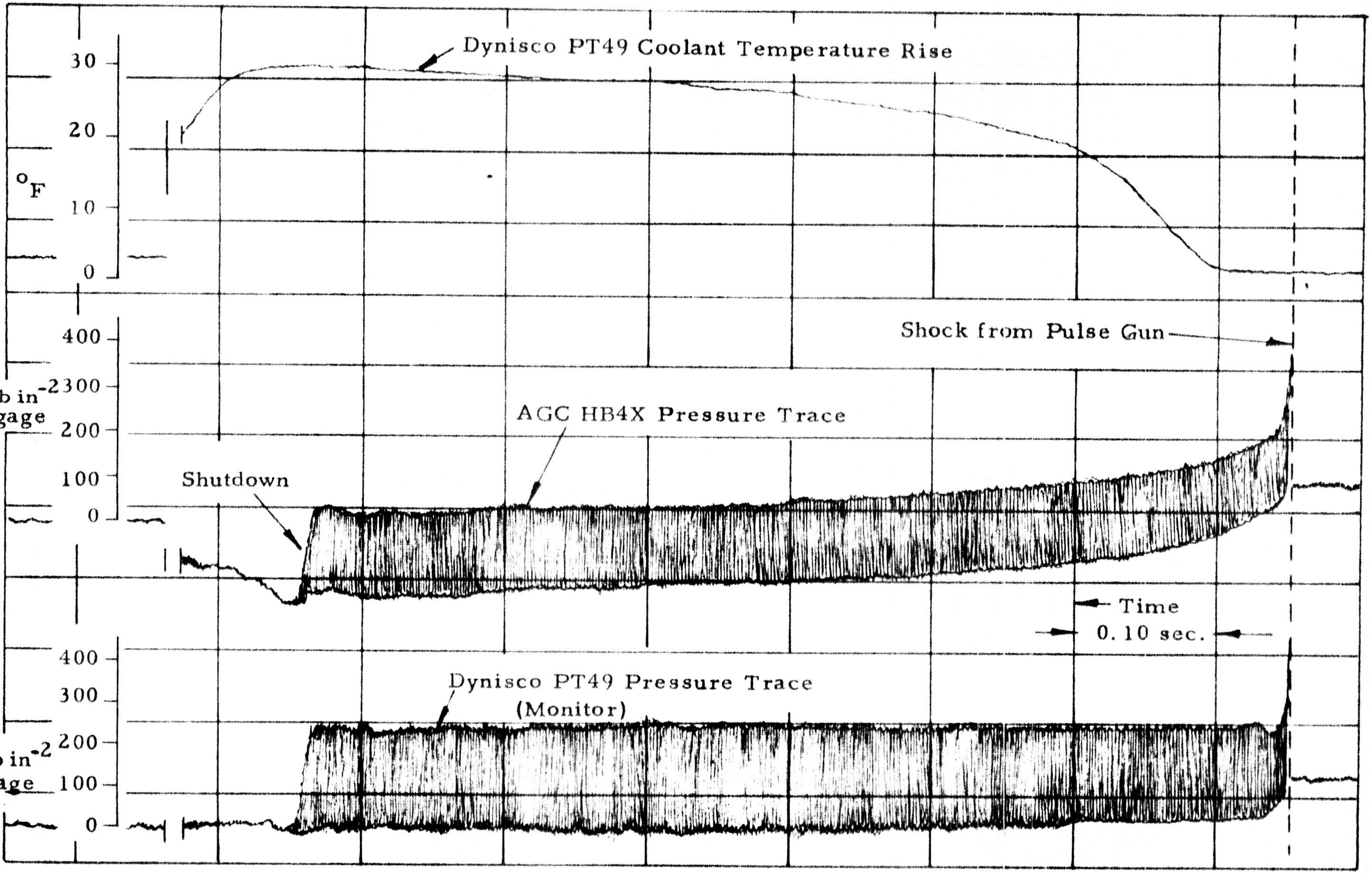
accumulation of dynamically compensated data. Helium bleed tube repairs have been made and the unit has been scheduled for more rocket motor tests with dynamic compensation.

b. Aerojet-General Model HB4X-1 Adaptor

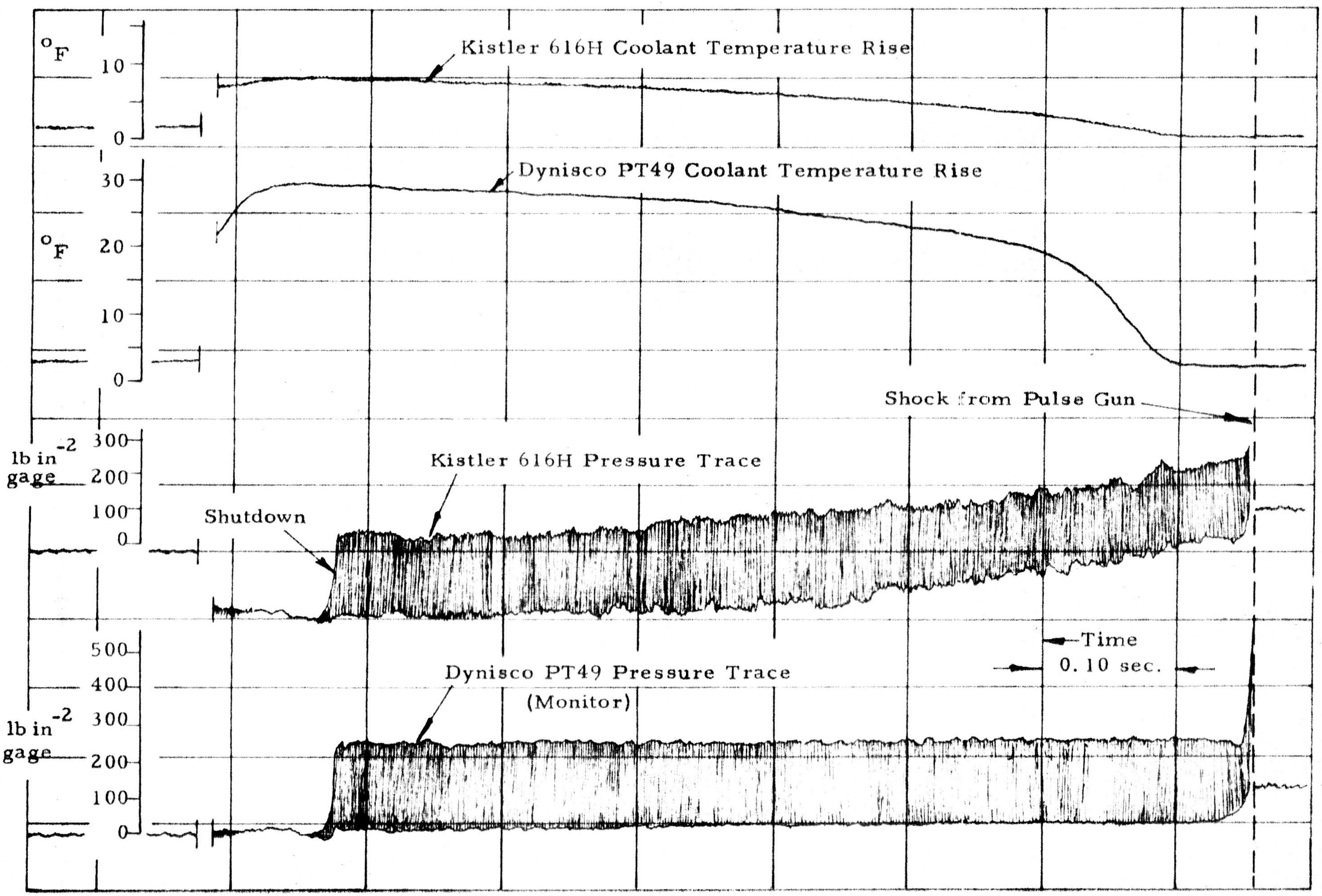
Thermal drift, as seen in the rocket motor test data from the HB4X in Figure 14, was very large for approximately 0.2 seconds after the start of combustion instability, decreasing gradually until thermal equilibrium in the transducer system was reached at about 0.5 seconds. About 3/8 inch of the probe end eroded; again with no apparent effect on transient data. Analysis of the first second of run time continues in an effort to learn more about the effect of stepped diameter passages on dynamic response. The damaged probe has been dressed to a shorter length for additional rocket motor tests. The excessive amount of probe erosion is attributed to the very thin wall at the probe end.

c. Kistler Model 616H

Coolant flow for the 616H, selected from coolant tests in the laboratory, was found to be insufficient for rocket motor testing. Although a flow of 0.130 lb/sec provided sufficient protection against burnout, a large thermal drift rate in transducer steady state output was experienced along with a sudden and very large shift at the start of combustion instability. The latter was overcome by increasing the coolant flow until, at a flow of 0.244 lb/sec, the sudden shift in steady state output at the onset of combustion instability was eliminated. Increasing coolant flow to 0.409 lb/sec had little effect and a large overall thermal drift persisted. Average coolant pressure was maintained at 975 psig and helium bleed pressure at 2.5 times peak chamber pressure. The test data presented in Figure 15 was taken with coolant flow at 0.244 lb/sec.



Oscillograph (Visicorder) Traces of AGC HB4X (#001) vs Dynisco PT49 (#21197)
for Rocket Motor Test No. A 1875



Oscillograph (Visicorder) Traces of Kistler 616H (#107) vs Dynisco PT49 (#21197) for Rocket Motor Test No. A 1879

FIGURE 15

C. Other Types of Transducers

Included in this section are two instruments which utilize different techniques for increasing transducer heat transfer capabilities.

1. Laboratory Evaluations

a. Kistler Model 616A

The Kistler model 616A shown in the FRONTISPIECE is a passage connected transducer assembly in which the diaphragm of a Kistler model 601A quartz transducer is located at the end of a very short passage in a water cooled adaptor. The adaptor has a 1/2 X 20 mounting thread running along 1/2 inch of its 5/8 inch reach.

A coolant flow of 0.126 lb sec^{-1} was established at the manufacturer's recommended 1000 lb in^{-2} gage average coolant pressure. The linear output, negligible hysteresis and low zero output drift, characteristic of the 601A transducers, appear in the static pressure calibrations. Coolant flow at constant coolant temperature and rated average coolant pressure had no effect on transducer output. A peculiar response to a shock input was obtained with the small passage filled with the nitrogen gas of the shock tube test section making it difficult to determine resonant frequency of the passage. However, dynamic performance in the SPG was excellent. Low heat flux testing indicated a negative thermal zero output shift of 0.2 percent F.S. per Btu sec^{-1} in^{-2} of total heat flux into the adaptor.

b. Photocon Model PRP200

The model PRP200 utilizes a semiconductor strain gage bridge, bonded to a square reduced section of a 1/8 inch diameter solid metal probe as a method of transduction. Strain, resulting from pressure applied to the end of the probe, is transmitted to the piezo-resistive gages mounted on the reduced section. Two small 0-rings near the end of the probe provide a pressure seal.

The static pressure calibrations in the evaluation of Appendix A have been translated to zero output at zero applied pressure. Since the first plot did not close at the end of a 42 point calibration made from zero to 2,000 lb in^{-2} gage, a second calibration was performed in which the process of applying pressure was reversed and the number of calibration points reduced to 18. Although indicated bridge current remained constant at 15 milliamperes, sensitivity increased slightly and the calibration curve nearly closed at the end point. Some effect of a zero adjusting circuit on transducer output, used to bring transducer output on scale, was suspected. A third calibration was made in which the zero adjust circuit was removed and transducer output read on a digital voltmeter. Results of the third calibration are accepted as the static performance of the transducer at a constant bridge current of 15 milliamperes.

A resonant frequency of approximation 26,700 cycles per second appears in the shock tube data with peak to peak oscillations equal to about one half the pressure step. The acceleration test, in which the transducer was protected from the shock wave by a steel plate, produced the same frequency. A beat frequency of 5000 cycles per second, accompanied by very high amplitudes, is seen in the data along with a frequency of approximately 100 kilocycles at significant amplitudes. Oscillations of small magnitude also occur at about 1 megacycle. It is impossible to accurately determine any one of the several frequencies displayed in the shock tube data. Considering the time increment associated with each oscillation in the data of photograph No. 1 of the Appendix, transducer resonant frequency ranges from 25,000 to 40,000 cycles per second.

The unit was removed from its adaptor, concentricity and tolerances were checked and 0-ring seals were replaced and lubricated. The unit was reassembled and leak tested to 2000 lb in^{-2} gage and shock tube tests were repeated. Results of the repeated tests, found in photographs Nos. 5 and 6 of the evaluation in Appendix A, indicate that displayed dynamic performance is inherent in the transducer and not the result of improper mounting or adaptation to test equipment. Although transducer output was greatly attenuated at low frequencies as measured in the Sinusoidal Pressure Generator, amplitude response was reasonably flat above 1500 cycles per second. This and the repeatability determined in the shock tube suggests the instrument may be calibrated and used for transient pressure measurements for very short runs in research rocket motors.

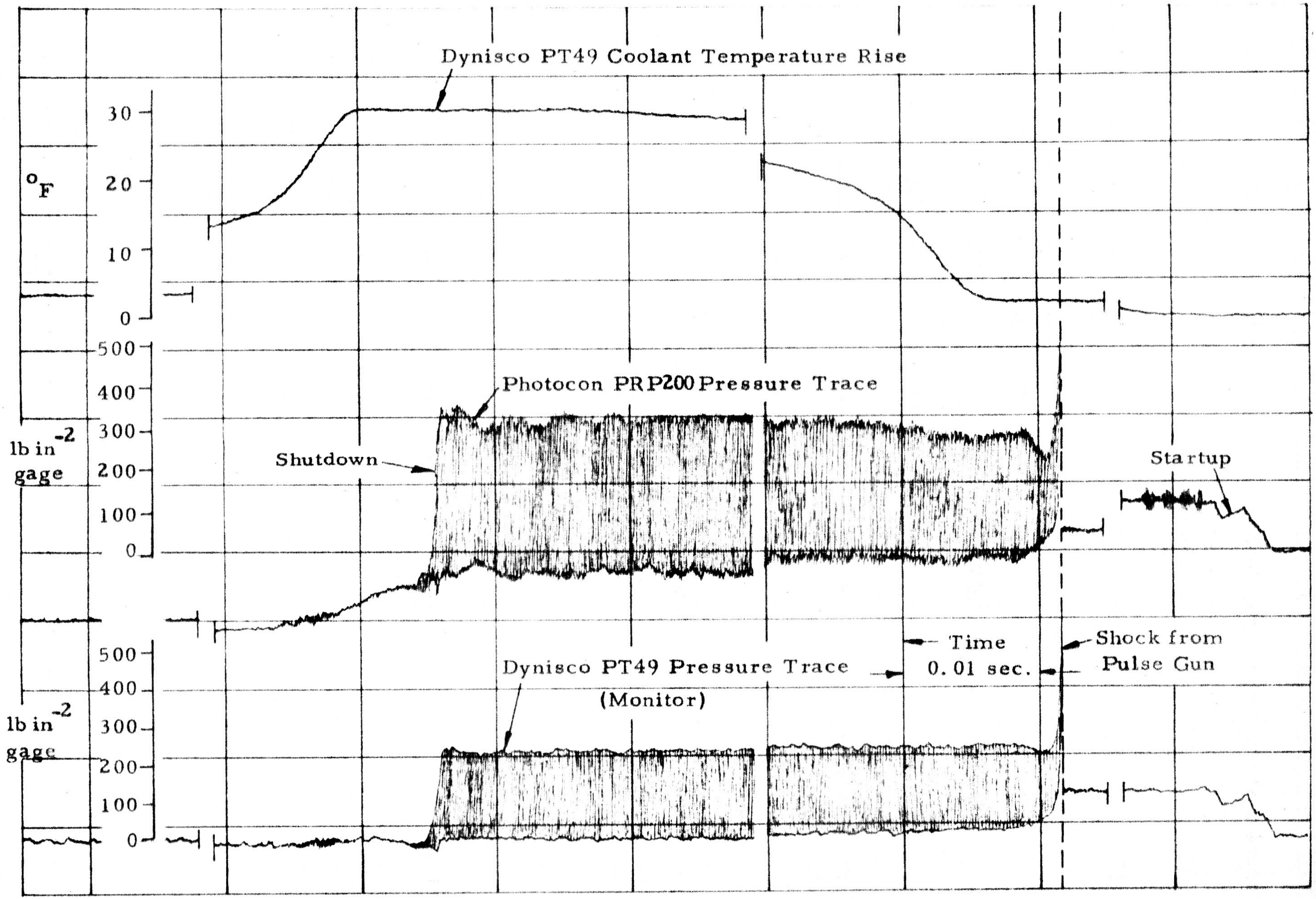
2. Rocket Motor Tests

a. Kistler Model 616A

Preliminary rocket motor tests on the 616A adaptor, in which a bare junction thermocouple replaced the transducer, indicated temperatures exceeding allowable working temperatures for the transducer at heat fluxes as low as 4.5 Btu sec^{-1} in^{-2}. Although the 616A had performed in rocket tests at other locations, with and without ablative compounds protecting the transducer diaphragm, the instrument was set aside in favor of testing the advanced Kistler transducer assemblies and scheduled for rocket motor tests beyond the research period.

b. Photocon Model PRP200

Three rocket motor tests were made to check dynamic performance, piston ablation, and 0-ring sealing under conditions of fully developed combustion instability. An increase in amplitude with time and considerable thermal drift is displayed in the rocket test data shown in Figure 16. No piston erosion or leakage occurred during the tests and 0-ring seals were intact after removal of the unit from the chamber. The data of Figure 16 is that recorded on the last rocket motor test. Growth in amplitude with time is not as great as in the two preceding runs. Since test conditions were repeated for all rocket motor tests, analysis of test data continues in an effort to find a satisfactory explanation for this change in dynamic response.



Oscillograph (Visicorder) Traces of Photocon PRP200 (#107) vs Dynisco PT49 (#21197) for Rocket Motor Test No. A 1883

FIGURE 16

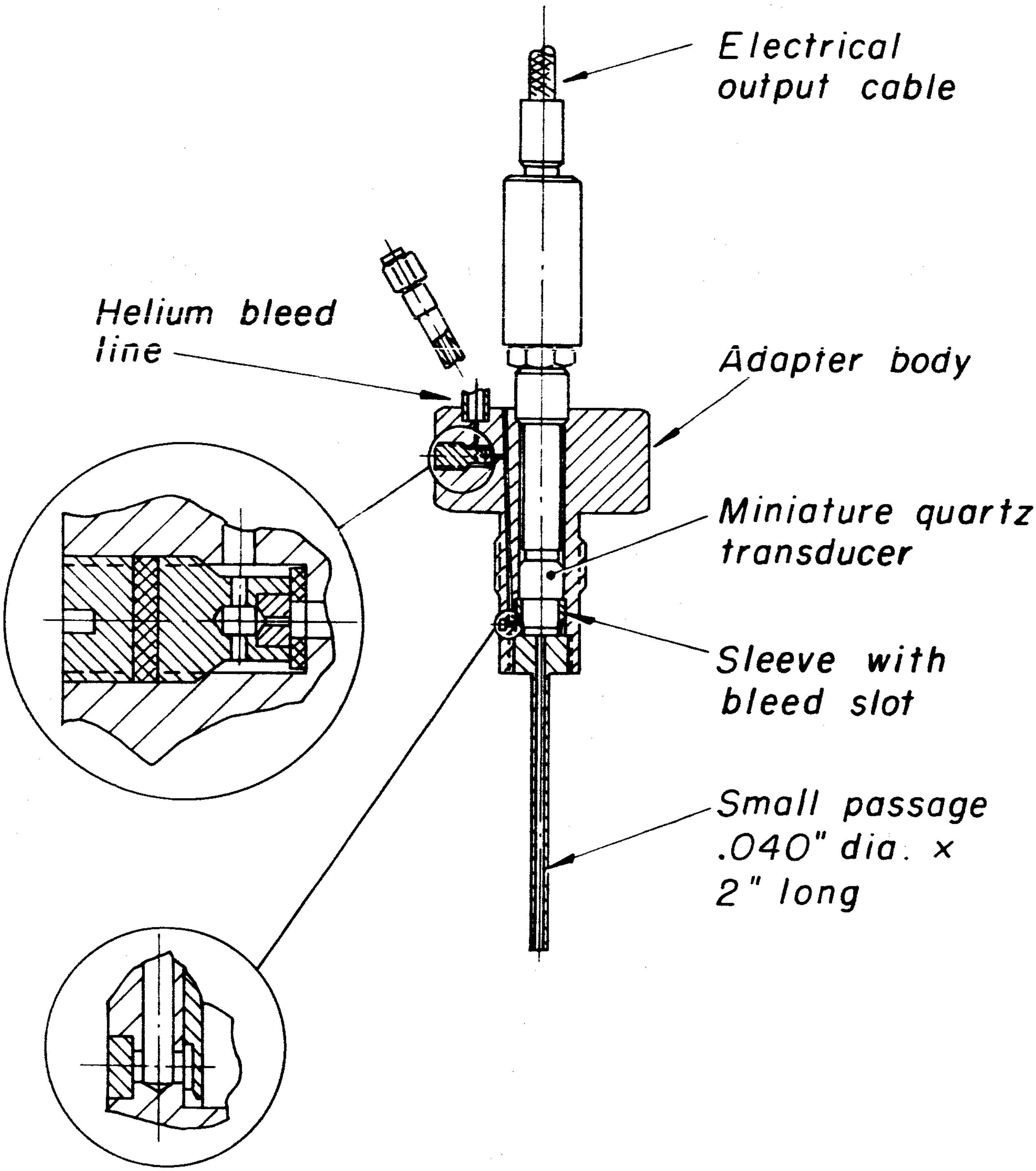
III. OTHER WORK

A. Dynamic Response of Small Passage Connected Transducers

Development of the Princeton Small Passage Technique as a transient pressure measuring device for use in liquid propellant rocket thrust chambers has met with considerable success and several transducer assemblies which utilize the technique are commercially available. Some of these are discussed in this report. A study in the dynamic response of small passage connected transducers, aimed at further improvement of the Small Passage Technique, was made to gain additional insight by adjusting various parameters and to establish a pattern of calibrating devices employing the technique.

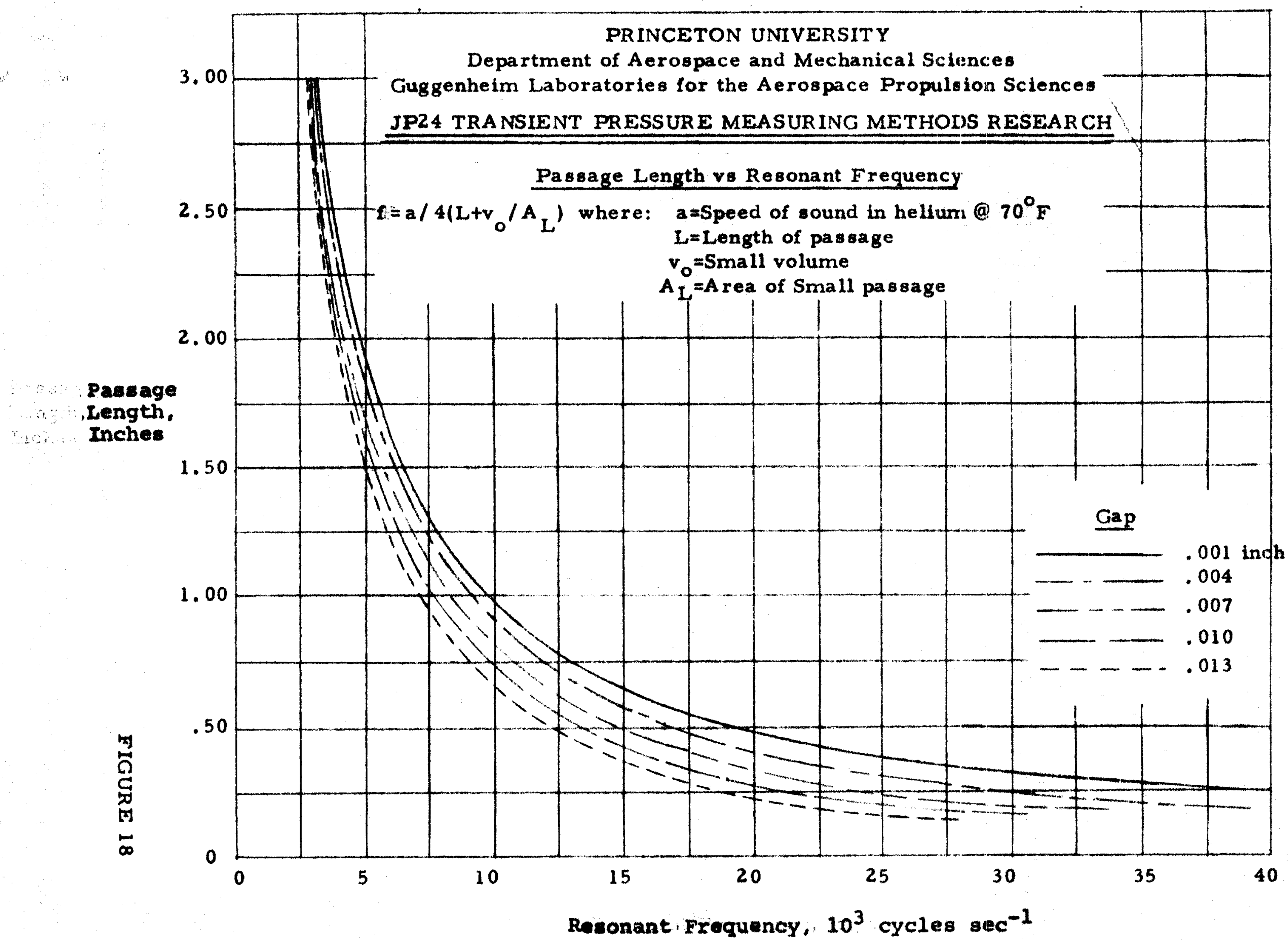
An uncooled version of the Guggenheim Laboratories G1029 Cooled Probe Adaptor was selected for the study and modified to facilitate parameter changes, particularly passage length and the small volume between the transducer diaphragm and the end of the passage. Figure 17 shows the GL030 adaptor and its component parts used for the study. Passage length was varied by unscrewing one probe and replacing it with another of different length. Helium mass flow was controlled by using different diameter orifices and adjusting helium supply pressure. Volume at the end of the passage was controlled by changing "gap" or distance between transducer diaphragm and the end of the small passage. This was best accomplished by making the helium bleed sleeve in two sections; a section containing the helium bleed slots and a spacer section which could be machined to a prescribed length.

A formula derived from an analysis by Reardon and Waugh, which predicts the response of passage connected pressure transducers, was modified to predict the resonant frequencies of various passage lengths and small volumes. The formula is found in Figure 18 with a theoretical plot of Passage Length vs Resonant Frequency for a number of gaps or small volumes using helium gas. Figure 19 is a plot for a range of gap dimensions (0.001 to 0.013 inches) using helium, hydrogen, and nitrogen gases. A plot for typical combustion gases is found in Figure 20.



GL030 Small Passage Connected
Transducer Adapter

FIGURE 17



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JP24 TRANSIENT PRESSURE MEASURING METHODS RESEARCH
Passage Length vs Resonant Frequency
f = a/4(L+vo/AL) where: a=Speed of sound in helium @ 70°F
L=Length of passage
vo=Small volume
AL=Area of Small passage
Gap
.001 inch
.004
.007
.010
.013
Passage Length, Inches
3.00
2.50
2.00
1.50
1.00
.50
0
0
5
10
15
20
25
30
35
40
Resonant Frequency, 10³ cycles sec⁻¹

FIGURE 18

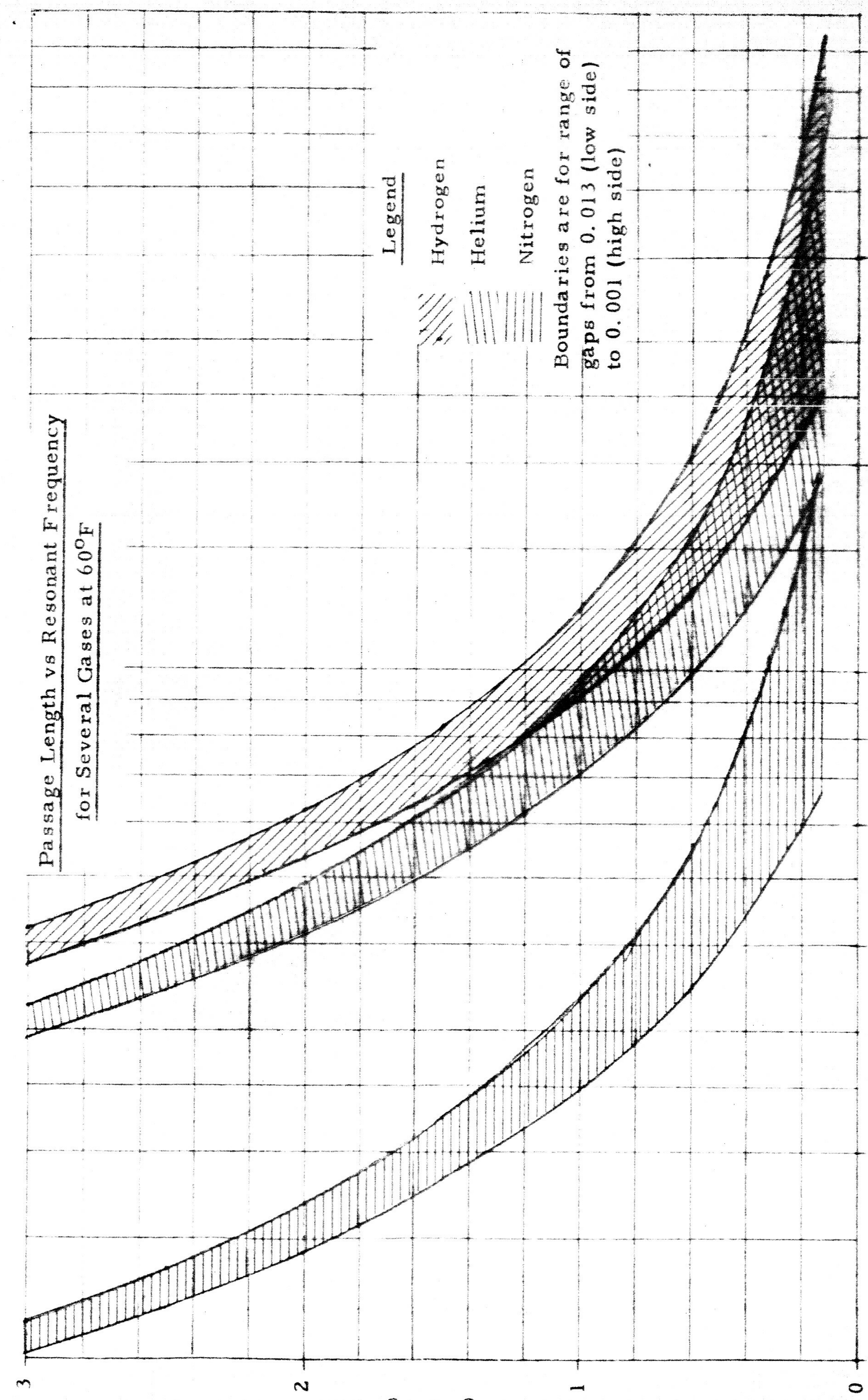

Passage Length vs Resonant Frequency
for Several Gases at 60°F
Legend
Hydrogen
Helium
Nitrogen
Boundaries are for range of gaps from 0.013 (low side) to 0.001 (high side)
Resonant Frequency, 10³ Cycles sec⁻¹
Passage Length, inches
0
1
2
3
1
2
4
6
8
10
20
40
60
80

FIGURE 19

Passage Length vs Resonant Frequency
of Several Liquid Propellant Combustions
for Maximum Rocket Performance
at 500 lb in^{-2} gage Chamber Pressure

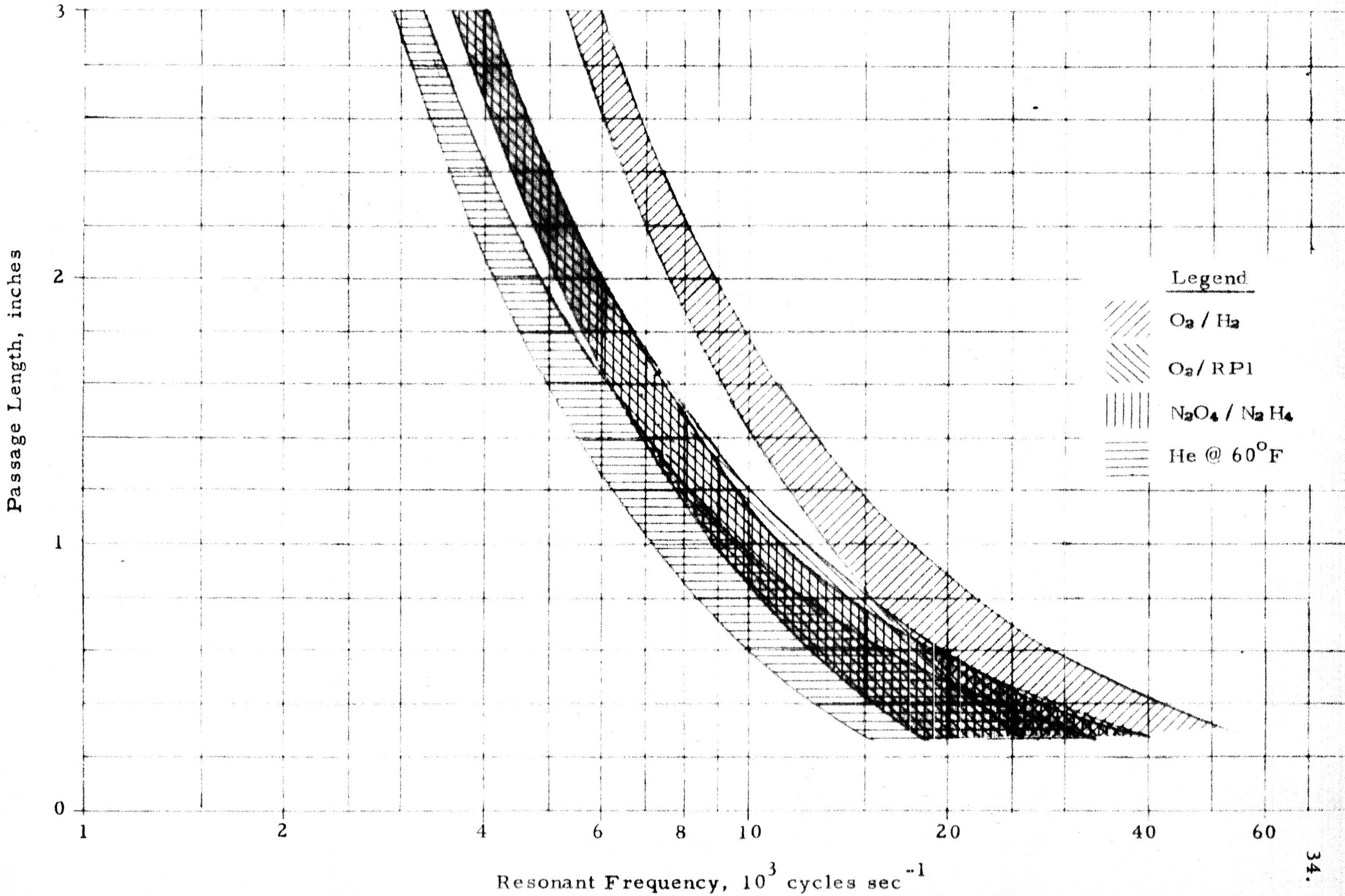
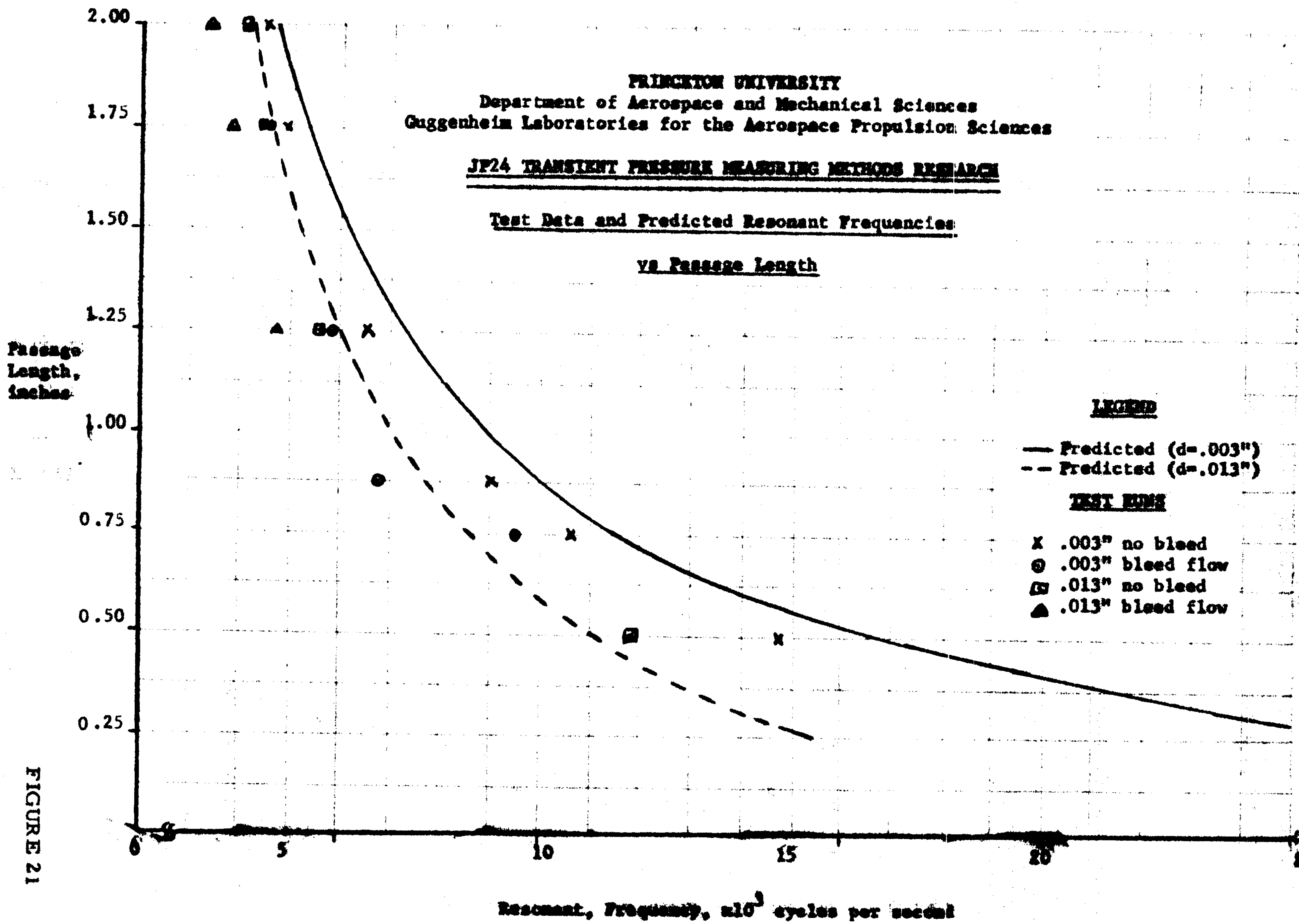


FIGURE 20

Tests were conducted with gaps of 0.003 and 0.013 inch. The smaller gap is a minimum to provide proper transducer diaphragm clearance and helium bleed flow. The larger gap was used to determine the effect of a large volume on performance. Theoretical results were based on a simple circular cross-section passage with a cylindrical small volume and assuming zero damping. Test results and predicted resonant frequencies agree favorably. Figure 21 shows test data for gaps of 0.003 and 0.013 inch at various passage lengths with and without helium bleed flow placed on a plot of predicted results. In the case of no helium bleed, a blank sleeve replaced the slotted helium bleed sleeve.

An analysis of a system involving geometry which deviates from the simple cylindrical case just presented would be tedious. Since changes in geometry are small, qualitative tests will suffice to determine the effect of geometry changes on performance. Changes in geometry involved a stepped diameter passage, a 0.003 inch chamfer and a shallow double cone chamfer at the end of the small passage. Test results, compared with the simple case for a passage length of 0.750 inch in Figure 22, show that the two-diameter probe increases the amplitude ratio and the true resonant frequency, the 0.003 inch chamfer increases amplitude ratio for both bleed flow and blank sleeve conditions and the double cone increases the amplitude ratio and also increases the true resonant frequency from 9500 cycles per second to 9600 cycles per second for the bleed flow case. A very interesting result is that a two step diameter passage produces a resonant frequency considerably higher than the predicted resonant frequency.

Another interesting result, previously mentioned and considered to be of importance at this time, is how the method of admitting helium to the small volume affects dynamic performance. The GL030 adaptor provided, during the course of study, a check on the HB3X-1 adaptor. The HB3X-1 evaluation disclosed wave distortions and a resonance at very high amplitude in the vicinity of 6000 cycles per second. The GL030 adaptor was assembled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JP24 TRANSIENT PRESSURE MEASURING METHODS RESEARCH
Test Data and Predicted Resonant Frequencies
vs Passage Length
LEGEND
Predicted (d=.003")
Predicted (d=.013")
TEST RUNS
.003" no bleed
.003" bleed flow
.013" no bleed
.013" bleed flow
Passage Length, inches
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0
5
10
15
20
25
Resonant, Frequency, x10³ cycles per second

FIGURE 21

Amplitude vs Frequency
for some Geometry Changes
Guggenheim Laboratories GL030 Adaptor
Small Passage Length = 0.750 Inches

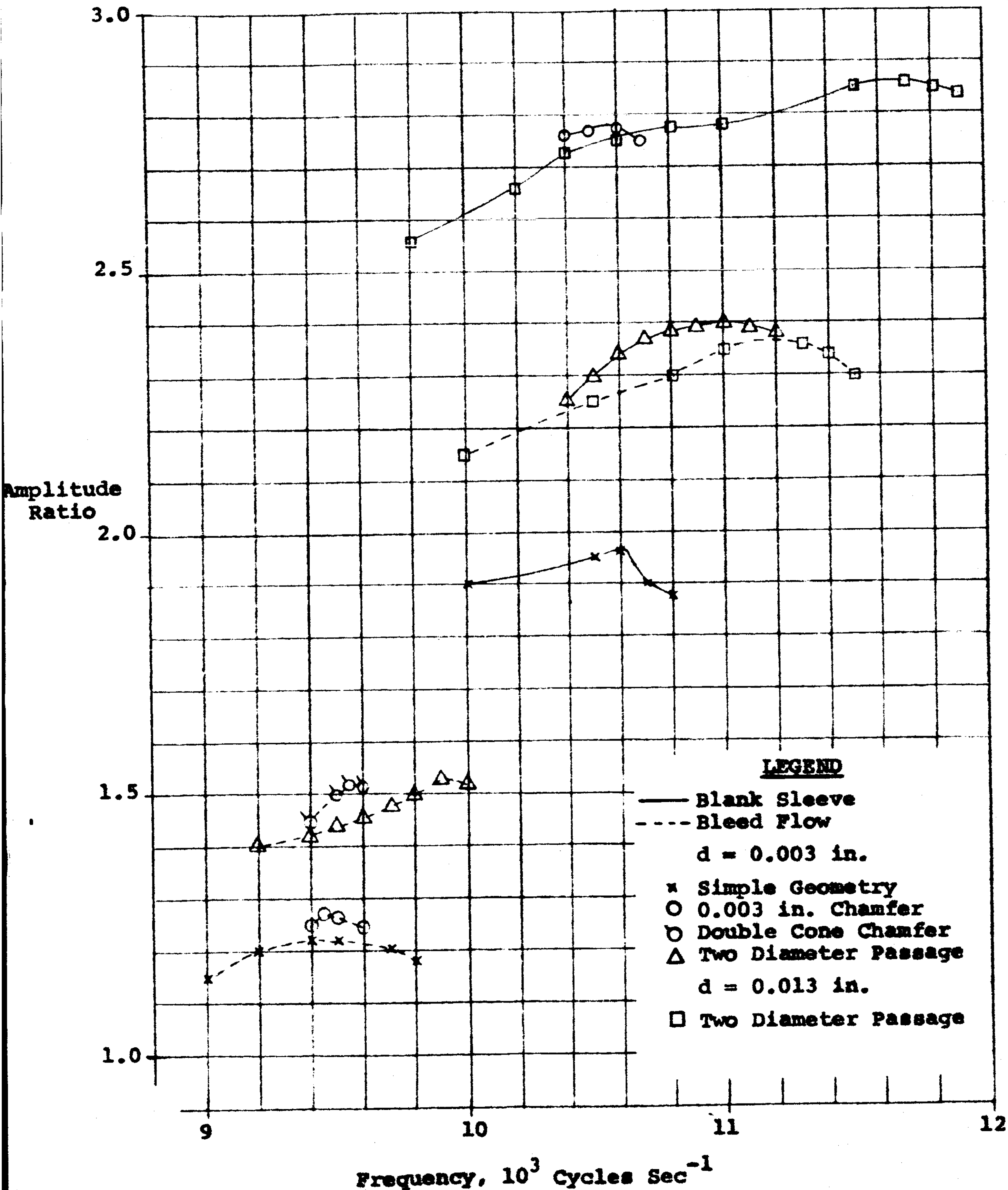


FIGURE 22

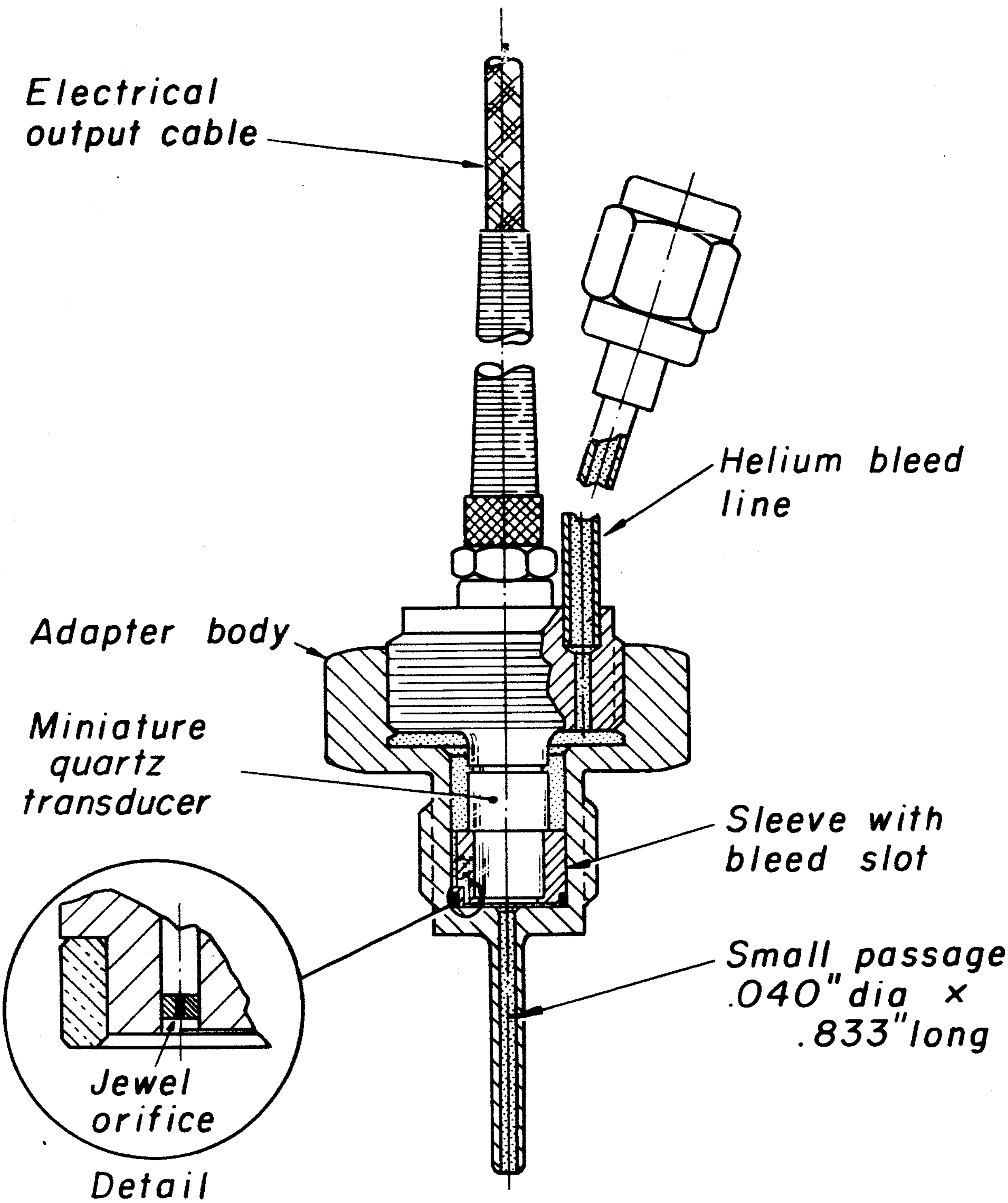
in the HB3X configuration except for the helium bleed sleeve which had four very small bleed slots symmetrically located to admit helium from a narrow annulus machined on the outside of the sleeve into the small volume between the end of the small passage and the transducer diaphragm. Helium was admitted directly to the small volume in the HB3X-1 through a single bleed hole as shown in Figure 23. Amplitude Ratio vs Frequency for both assemblies is presented in Figure 24. A full report on this work (Princeton Aeronautical Engineering Report No. 595q) is currently in preparation.

B. Computer Analysis of the Transient Response of Pressure Transducers to Shock Inputs

Work continued during this period on several methods for the evaluation of transducers using pressure steps produced by a shock tube. Much effort was spent early in the period on a literature search that led to programming three methods: straight line, staircase, and pseudo-rectangular pulse for the analysis of a theoretical damped sine wave for amplitude ratio and phase lag versus frequency. These methods have been tested for a variety of sampling intervals (spacing) and number of cycles (truncation) with generally satisfactory results for close spacing and little truncation. The methods will shortly be used to evaluate the effects of increased spacing intervals and truncation on the results. Two other methods called the triple differentiation method and Fourier function method have been developed mathematically and are now being programmed.

A damped sine wave derived from the theoretical curve has been hand plotted and photographed for reading on an optical scanner which will provide punched card input for the computer as a check on the trace and reading errors encountered in handling the Polaroid photographs of the oscilloscope outputs from the shock tube test of an actual transducer.

A large number of transducers have been tested on the shock tube and the photographic results will be analyzed for amplitude ratio and phase lag by the method found to be most suitable. It is hoped that the phase lag results will be found to be useful as well as an improvement in amplitude ratio results. The complete work will be presented in Princeton University Aeronautical Engineering Report No. 595s, soon to be published.



AGC GEMSIP Helium Bleed HB3X-1 Transducer Adapter

FIGURE 23

Amplitude Ratio vs Frequency

Aerojet GEMSIP HB3X-1 and
Guggenheim Laboratories GL030

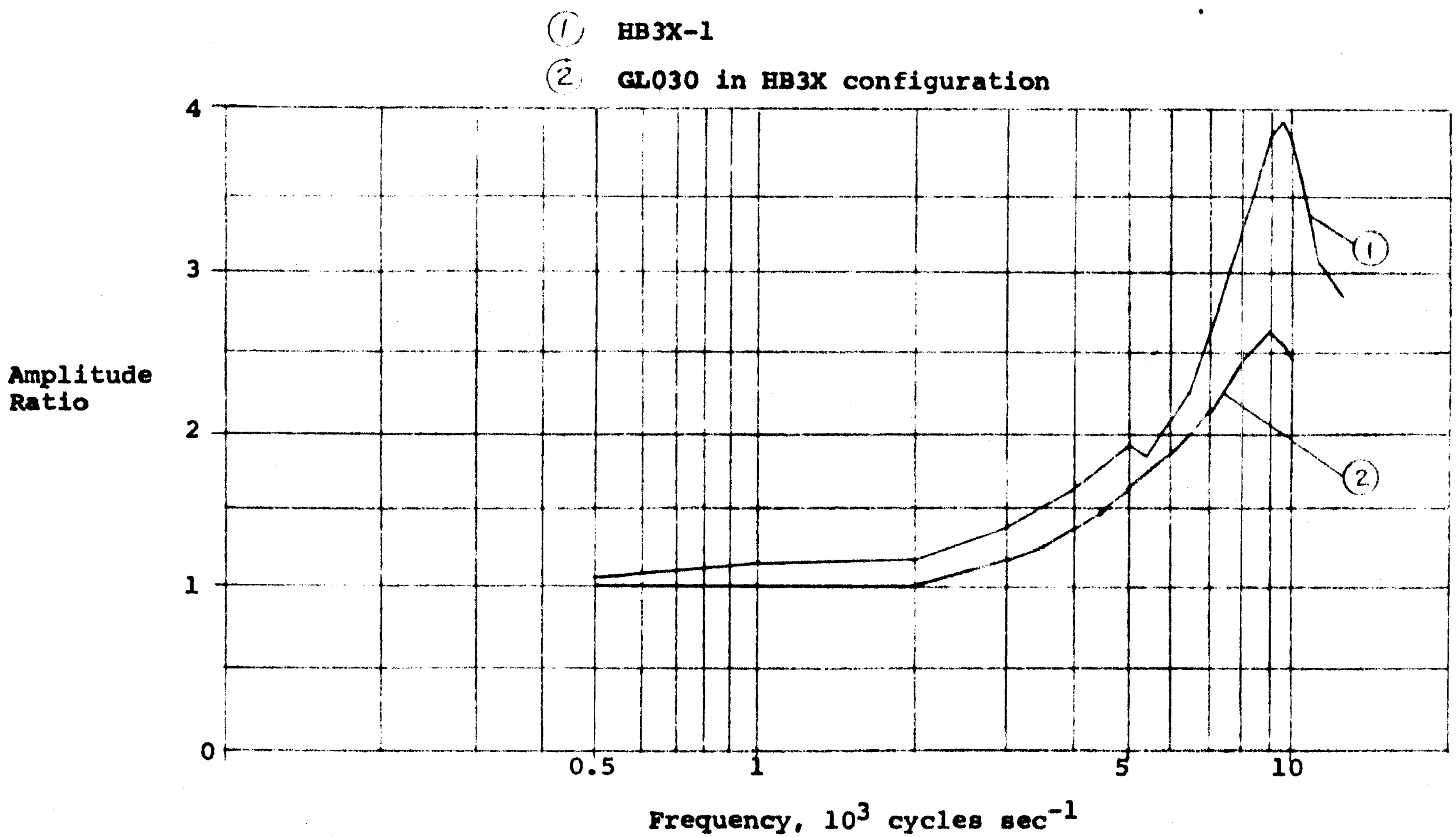


FIGURE 24

C. Heat Transfer Measurements with Water Cooled Flush Diaphragm Transducers

The feasability of using water cooled flush diaphragm transducers as heat flux gages depends largely on the ability to determine extraneous heat fluxes or that part of the total recorded heat flux contributed by heat flow through the transducer body. Laboratory tests at low heat flux values, using a cooled copper assembly to control transducer environment, an oxy-acetylene torch for heat input and Dynisco model PT134 transducers as a heat flux gage, indicated 15 to 45 percent error in heat flux measurements when using the transducer diaphragm area as a heat transfer area.

Heat flux was determined by measuring coolant flow, coolant temperature rise, using a coolant heat capacity of unity and the transducer diaphragm area as a heat transfer area to provide a uniform base for heat flux comparisons. Results of over 40 test runs yielded lateral heat flow (heat flow through transducer body) values ranging from 12 to 43 percent of the total recorded heat flux.

An extensive series of rocket motor tests, in which rocket test conditions were repeated, were made with three model PT134 transducers. For a given transducer for nearly identical test conditions, heat flux data agreed within 7 percent and among the three transducers showed agreement within 9 percent. This series of tests was made in a large diameter cylindrical motor where heat transfer is expected to be the same along a circumferential element of the inner chamber wall during fully developed transverse combustion instability and transducers placed along this element should receive the same direct heat flux. Based on a temperature difference of $200^{\circ}F$ between rocket chamber wall and transducer coolant, calculated lateral heat flow in the PT134 amounted to 16 percent of the 8 Btu sec^{-1} in^{-2} total heat flux recorded. Total heat flux was consistently 11 percent higher than that indicated by a monitoring PT49C transducer. This was expected since the transducer body heat transfer area of the PT134 is 1.18 in^2 compared to the PT49 area of 1.08 in^2.

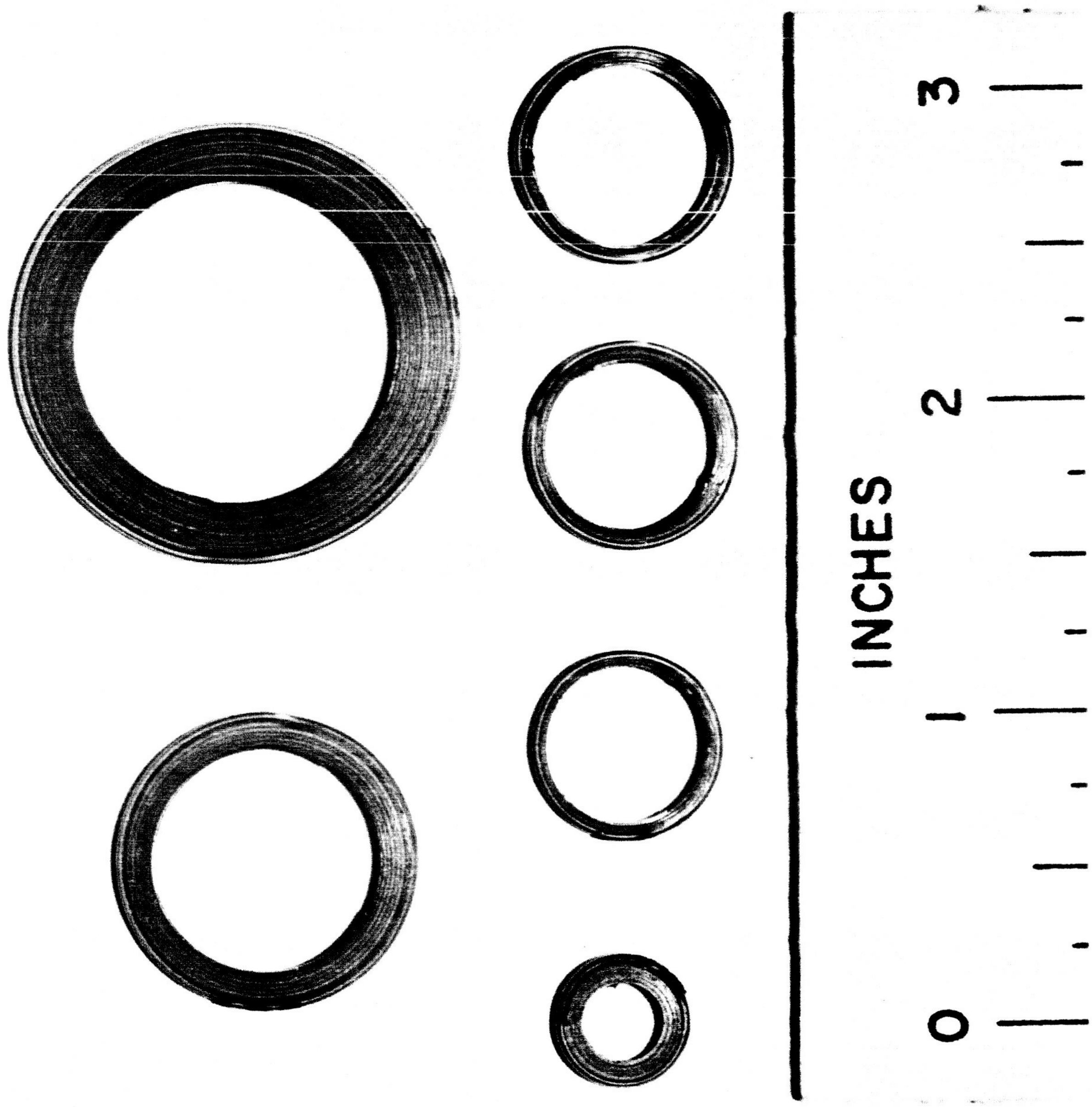
Laboratory tests at low heat flux levels showed a 20 percent greater heat transfer with a transducer to adaptor clearance of 0.0005 inch than with a clearance of 0.0065 inch. Evidently the clearance between the transducer and the chamber wall acts as a thermal barrier during steady state conditions and may account for some extremely high indicated lateral heat flows (65% of total heat transferred to coolant), previously reported for the Dynisco model PT134, during combustion instability when hot gases are being "pumped" along the transducer body. A detailed report, Princeton University Aeronautical Engineering Report No. 595r is currently in preparation.

D. Transducer Gaskets and Sealing

A solution to the problem of sealing transient pressure measuring transducers involves several factors. As instruments become smaller in size, pressure sealing is reduced but manufacturing very small gaskets to perform in extreme temperature environs and which will remain resilient enough to seal an expanding and contracting joint becomes increasingly difficult. The method of retaining a transducer in its cavity along with transducer geometry and ruggedness dictate to gasket geometry and gasket loading. A number of shapes and materials serve well, regardless of size, as "one-shot" gaskets or for repeated testing where environmental conditions are mild and hold fairly constant. However, for service in advanced rocket booster engines, where hard starting, high pressures, and extreme temperature changes are prevalent, special gaskets are required.

Sealing was recognized as a major problem early in Transient Pressure Measuring Methods Research. Several materials in various shapes performed successfully in research rocket motors where the limiting factors of transducer size and geometry, operating pressures and temperatures, and reliability requirements were not too severe. As operating conditions became increasingly severe, efforts to find or develop a new gasket increased.

A coordinated effort with the Flexitallic Gasket Company of Camden, New Jersey was initiated to develop a seal fashioned after that company's spiral wound gasket, a type of seal which has performed remarkably well in a wide variety of applications for many years. A number of gaskets were made to fit the Dynisco model PT49AF transducer. Gasket construction was of 304 stainless steel wrap with asbestos filter designed to seal while flexing 0.010 inch. The maximum allowable torque of 30 in-lb on the transducer retaining screws did not provide sufficient gasket loading for the degree of gasket hardness, a limiting factor which persisted with all of the PT49 models (see plot of Transducer Zero Output vs Applied Torque for transducer PT49CF-2M, S/N 21208 in the evaluations of Appendix A). Gasket loading was calculated for non-lubricated, stainless steel in steel screw threads with standard steel washers for bearing and a new gasket was designed about this criteria by Flexitallic. Gasket construction was of stainless steel wrap with teflon filler and of such hardness that sealing against 2000 psi nitrogen gas pressure at ambient temperature was realized at 20 in-lb of torque on each retaining screw. The gasket yielded to loading at 22 in-lb, was compressed 0.010 inch at 30 in-lb of torque on each screw and returned to original thickness after a full static pressure calibration on the transducer. No leakage occurred in rocket motor tests up to 1200 psi chamber pressure and rocket wall temperatures up to 450°F and the gasket was accepted for use with the Dynisco PT49 transducers. Gaskets of 1/16, 1/10, and 1/8 inch thickness, designed to locate the transducer diaphragm with respect to the inner chamber wall (from flush position to 1/16 inch recess), were also tested with very favorable results. Several gaskets showed no signs of leakage or deterioration after more than twenty rocket firings. An array of gaskets for other transducers, all of which gave excellent performance, appear in Figure 25.



FLEXITALLIC TRANSDUCER GASKETS

Figure 25

IV. CONCLUSION

Laboratory evaluations of transient pressure transducers that are currently available and prototypes of advanced models show a considerable capability for measurement of dynamic pressures according to various tests conducted as part of this research. The results must be compared with tests in rocket motors during transient and oscillatory combustion to establish the correlation between data taken in the laboratory and in actual use.

Although recent transducers and new techniques show a significant improvement in the capability for making satisfactory measurements of dynamic pressures in rocket thrust chambers, much remains to be done in the development of instruments and their associated systems. Additional work is needed on laboratory evaluation techniques to develop the apparatus and its operation. More work is needed on the theoretical and analytical aspects of data acquisition and reduction as well as the handling of the signals. The severe environment and restrictive mounting conditions involved in rocket test and operation must be recognized as primary factors in successful transient pressure measurement.

A further discussion of these conclusions will be found in the final report.

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Department of Aerospace and Mechanical Sciences
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FORM NO. 93e

JP-24 LABORATORY EVALUATION PROCEDURE FOR CURRENT WATER-COOLED FLUSH DIAPHRAGM TRANSIENT PRESSURE TRANSDUCERS

Type of Transducer: Four Arm Strain Gage

Manufacturer: Dynisco Model: PT49CF-2M Serial: 21208

Other Data:

Requested by: MFSC Conducted by: J.T., G.W., & F.S.

Approved by: J.P.R.

Date Start: 7-22-64 Date Stop: 8-10-64

A. Inspection	Initial Time Date
1. Inspect transducer, especially for flaws or damage with a stereo-microscope and Zyglo as necessary, noting cracks, dents, imperfect welds, etc. (Attached photos or sketches as required). Surface scratches on diaphragm	7-22-64 F.E.S.
2. Measure transducer for compliance with outline drawing. Note deviations: None	7-22-64 F.E.S.
3. Measure leakage resistance from all active pins to ground using the volt-ohmyst. Leakage resistance = 500 megohm.	7-22-64 F.E.S.
4. For strain gage type transducers, measure resistances using the Wheatstone bridge. Input resistance = 351.6 ohms. Output resistance = 350.4 ohms.	7-22-64 F.E.S.

B. Coolant Testing	Initial Time and Date
1. Install transducer in static test system in accordance with instructions dated 2 June'64 for coolant flow tests and static pressure calibrations. Use Δp–ΔT fittings, coolant inlet filter, coolant outlet sight-glass, and selected gaskets. N. B. These fittings are to remain on transducer throughout the evaluation. Connect transducer to instruments and auxiliary equipment. Follow manufacturer's procedures for the adjustment of auxiliary equipment and allow recommended warm-up time.	8-4-64 F.E.S.

Transducer gasket Flexitallic Adapter gasket ———

Δp–ΔT Set No. 12 Max. Torque 30 in. lb. Per Screw

Torque, in. lb.	0	2	4	6	8	10	15	20	25	30
Output, mv	.95	.94	.96	.95	.89	.83	.73	.63	.55	.50

(Zero Shift -30 psi)

Auxiliary equipment Serial No(s) and control settings

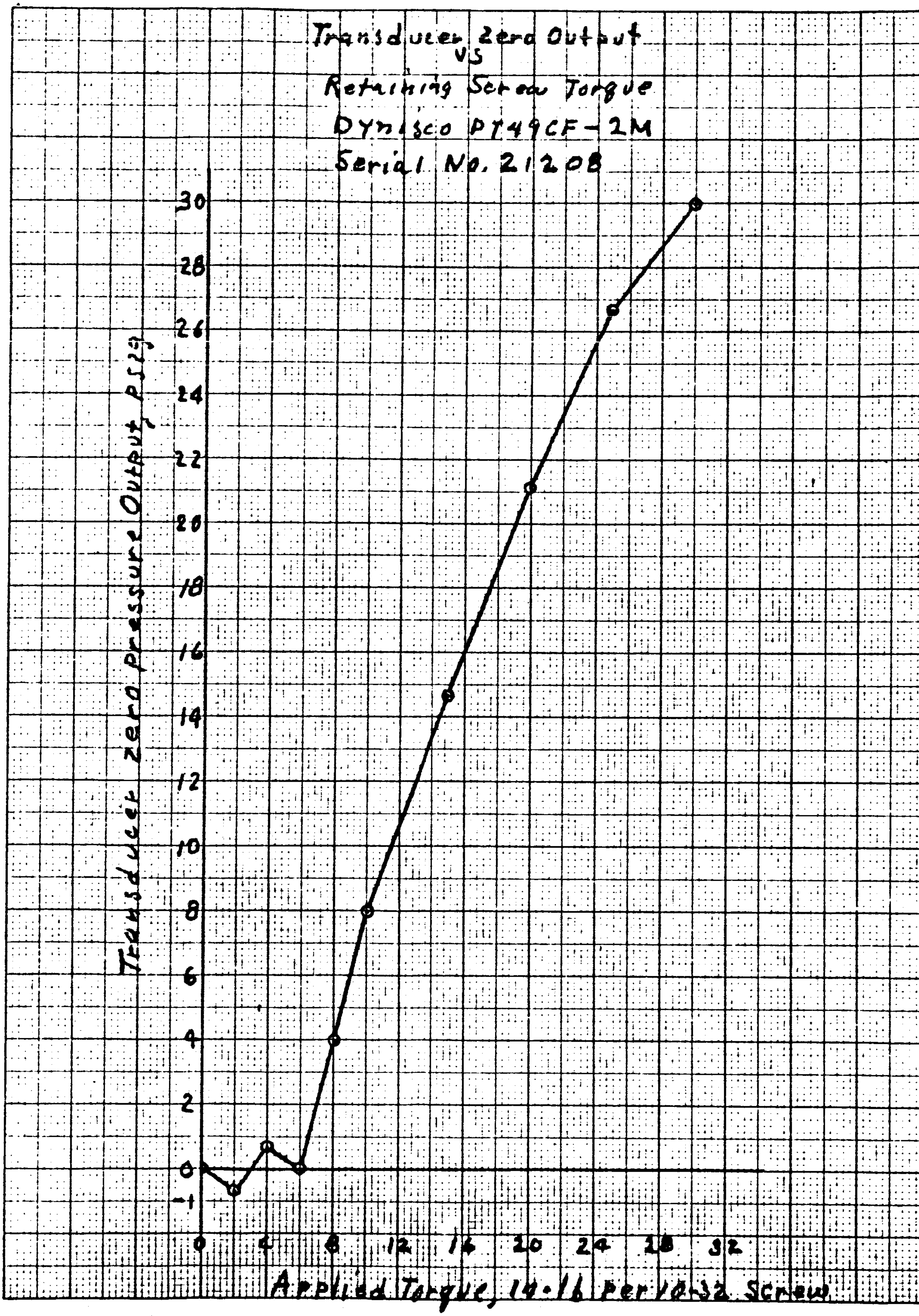
2. Attach coolant and instrumentation lines for coolant flow rate vs pressure drop test at average coolant pressure 175 psig. Flow meter No. 3/16-5. — 8-4-64 F.E.S.

ΔP Correction	p in psig	p out psig	Coolant Flow cps	Coolant Flow lb/sec	Transducer Output mv	Transducer Output psig	Coolant Temp. mv	Coolant Temp. °F
	0	0	0	0	.53		.9	73
-7.1	310	40	146.9	.1420	.43	-6.7	"	
-6	290	60	135.6	.1312	"	"	"	
-4.7	270	80	121.5	.1175	"	"	"	
-3.7	250	100	107.7	.1042	"	"	"	
-2.7	230	120	91.9	.0889	"	"	"	
-1.7	210	140	73.6	.0712	"	"	"	
	0	0	0	0	.51		"	

3. Reverse coolant flow by changing lines at Δp–ΔT fittings and repeat first two flow data points of item 2. — 8-4-64 F.E.S.

p in psig	p out psig	Coolant Flow cps	Coolant Flow lb/sec	Transducer Output mv	Transducer Output psig	Coolant Temp. mv	Coolant Temp. °F
0	0	0	0	.51		.9	73
310	40	156.8	.1518	.44		"	
290	60	144.1		.44		"	

(7% inc.)



K&E 10 X 10 TO 1/2 INCH 46 1323
7 X 10 INCHES
KEUFFEL & ESSER CO.

B. Coolant Testing (cont'd)	Initial Time and Date
4. Return coolant lines to original position and repeat item 2 at increasing average coolant pressure in 50 psi increments until pressure drops versus flow rate data shifts significantly. Report data after each coolant test.	8-5-64 J.C.S.

Average coolant pressure 75 psig

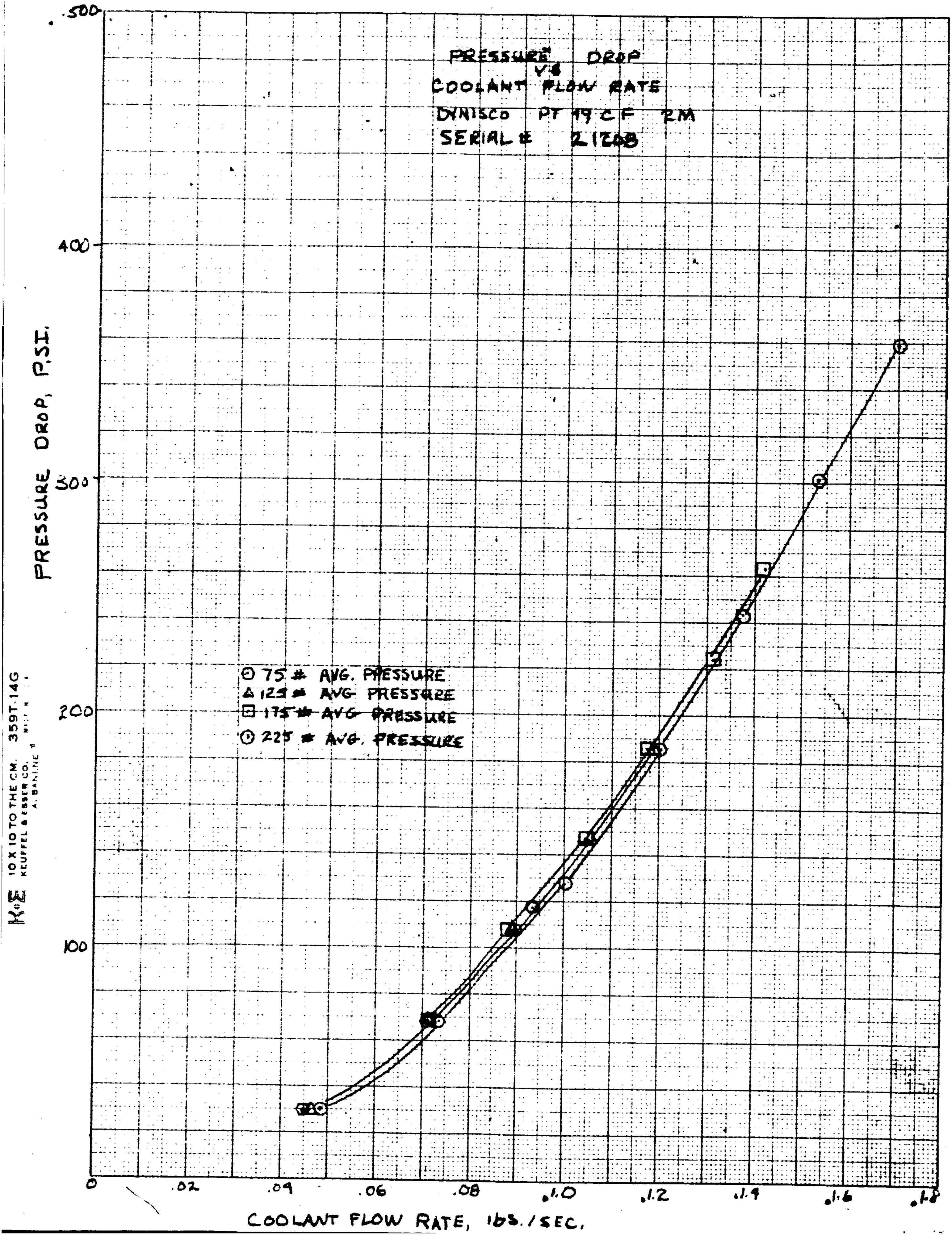
ΔP Correction	P in psig psi	P out psig	Coolant Flow cps	Coolant Flow lb/sec	Transducer Output mv	Transducer Output psig	Coolant Temp. mv	Coolant Temp. °F
	0	0	0		.53		.9	73
-3	135	15	96.2	.0934	.49		"	
-2.7	130	20	91.8	.0891	.49		"	
-1.7	110	40	73.0	.0708	.50	-3	"	
-0.7	90	60	46.1	.0447	.50		"	
	80	70	15.1		.50		"	
	0	0	0		.53		"	

Average coolant pressure 125 psig — 8-5-64 J.C.S.

ΔP Correction	P in psig	P out psig	Coolant Flow cps	Coolant Flow lb/sec	Transducer Output mv	Transducer Output psig	Coolant Temp. mv	Coolant Temp. °F
	0	0	0		.53		.9	73
-4.8	220	30	122.3	.1187	.48	-4.7	"	
-3.8	200	50	108.4	.1050	"		"	
-2.7	180	70	92.7	.0897	"		"	
-1.8	160	90	73.6	.0712	.47		"	
-0.8	140	110	47.7	.0463	.48		"	
-.0	0	0	0		.53		"	

Average coolant pressure 225 psig — 8-6-64 G.B.W.

ΔP Correction	P in psig	P out psig	Coolant Flow cps	Coolant Flow lb/sec	Transducer Output mv	Transducer Output psig	Coolant Temp. mv	Coolant Temp. °F
	0	0	0		.44		.9	73°
-10.8	410	40	175.5	.1700	.31	-2	"	
-8.5	380	70	158.5	.1535	"		"	
-6.6	350	100	141.9	.1374	"		"	
-5	320	130	124.2	.1205	"		"	
-3.4	290	160	103.1	.1000	.32		"	
-1.9	260	190	75.8	.0734	.32		"	
-0.9	240	210	50.0	.0485	.32		"	
	0	0	0		.42		"	


PRESSURE DROP
VS
COOLANT FLOW RATE
DYNISCO PT 49 C F 2M
SERIAL # 21208
⊙ 75 # AVG. PRESSURE
△ 125 # AVG PRESSURE
⊡ 175 # AVG PRESSURE
⊙ 225 # AVG. PRESSURE
PRESSURE DROP, P.S.I.
COOLANT FLOW RATE, lbs./SEC.
500
400
300
200
100
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
K+E 10 X 10 TO THE CM. 359T-14G
KEUFFEL & ESSER CO.

B. Coolant Testing (cont'd)	Initial Time and Date
5 5. Disconnect signal lead and repeat item A3. Leakage resistance 1000 meg-Ω.	8-8-64 GBW.
6. Connect signal lead and leave transducer energized. Report coolant test data.	
7. Tag transducer for coolant conditions as follows: a. Inlet Pressure 285 psig. b. Outlet Pressure 65 psig. c. Average Coolant Pressure 175 psig. d. Coolant Flowrate .125 lb./sec. N. B. All testing unless specifically directed otherwise, is to be carried out under the above conditions until the transducer is re-evaluated.	
8. With coolant flowing observe zero reading during a one hour period at 5-minute intervals. Report any significant shift in zero.	8-8-64 GB,W.

Time of Day	Output mv	Time of Day	Output mv	Time of Day	Output mv
2:25	.41	2:50	.40	3:15	.395
2:30	.40	2:55	"	3:20	.395
2:35	"	3:00	"	3:25	.395
2:40	"	3.05	"		
2:45	"	3:10	.395		

2/20 8

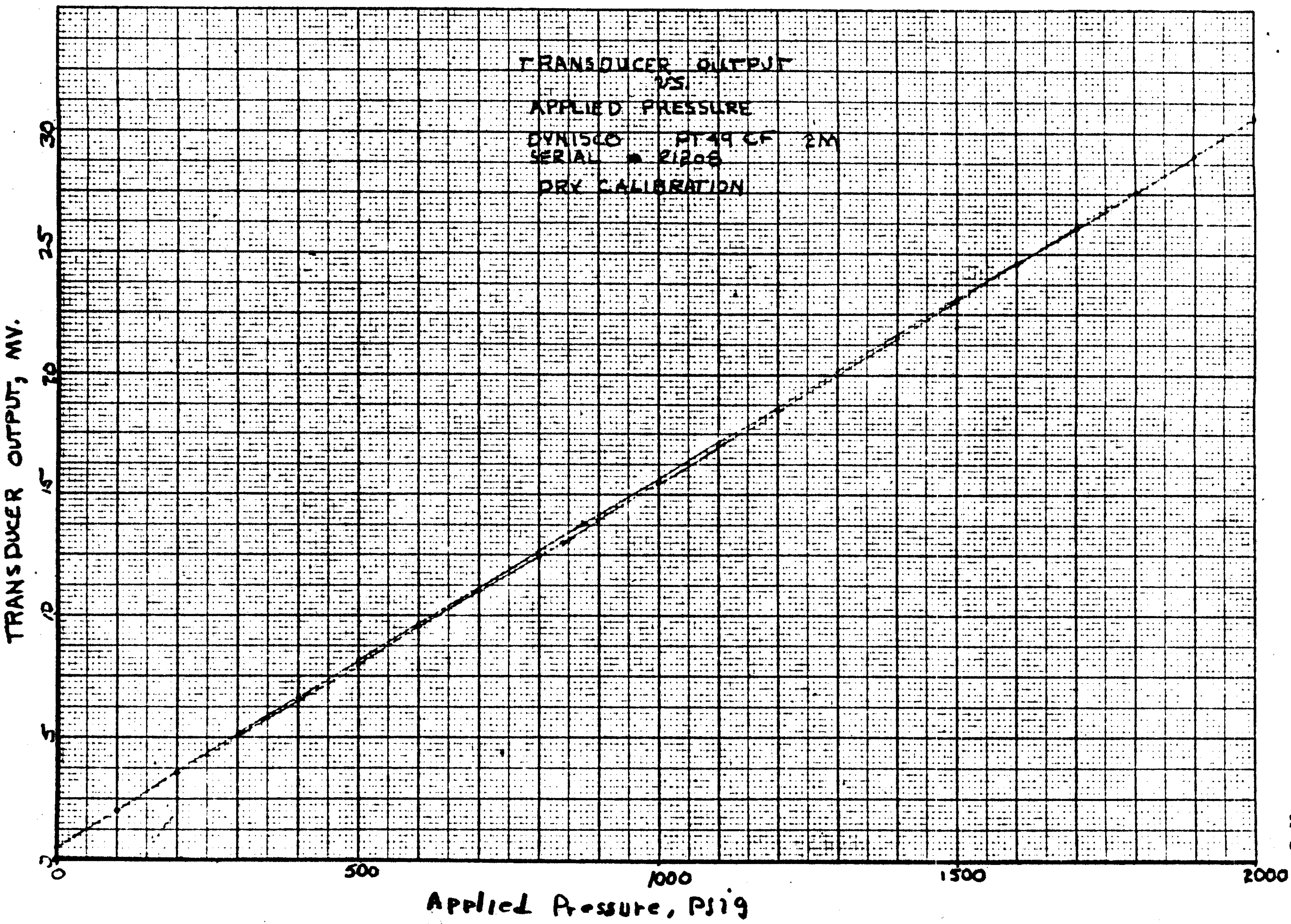
C. Static Testing	Initial Time and Date
1. If procedure has been interrupted, repeat Item B1 and B4. Completely purge coolant passages of water with dry nitrogen gas from static test panel at 20 psig max. Leave coolant lines disconnected.	
2. Apply 2000 psig to transducer. Insert on appropriate voltage divider to bring output on the calibrator scale. Divider ratio = __________. Release applied pressure.	

3. Apply pressure in 100 psi steps to 2000 psig and return in equal steps to zero pressure.
N. B. Care must be taken to approach each pressure in the particular direction of travel to avoid any masking of hysteresis or other effects.
Computing identification 208-3.

Ascending Pressure Output (mv)	Applied Pressure (psig)	Descending Pressure output (mv)
.52	0	.51
2.02	100	2.00
3.50	200	3.54
5.01	300	5.06
6.50	400	6.58
7.99	500	8.09
9.51	600	9.59
11.00	700	11.09
12.49	800	12.60
13.99	900	14.10
15.49	1000	15.60
16.99	1100	17.10
18.50	1200	18.60
20.00	1300	20.10
21.49	1400	21.59
23.01	1500	23.08
24.51	1600	24.60
26.02	1700	26.09
27.52	1800	27.57
29.04	1900	29.05
30.54	2000	30.54

Ascending Pressure ↓ — Descending Pressure ↑

NO. OF PTS.	IDENTIFICATION	SLOPE	Y-INTERCEPT	AVG. DEV.
42	2083	1.5013051E-02	.52790043	4.0532174E-02

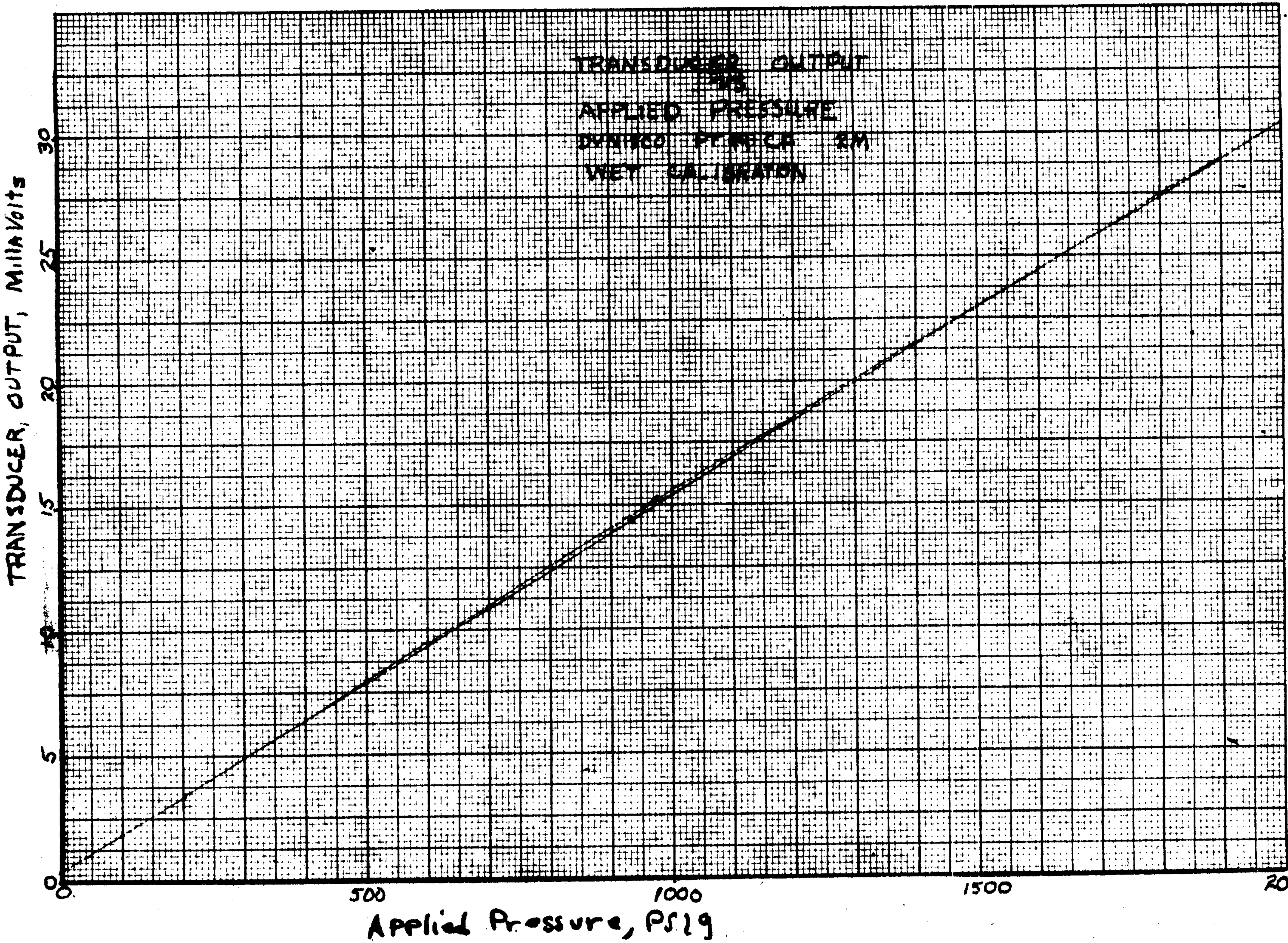

TRANSDUCER OUTPUT
VS.
APPLIED PRESSURE
DYNISCO PT 49 CF 2M
SERIAL 21208
DRY CALIBRATION
TRANSDUCER OUTPUT, MV.
0
5
10
15
20
25
30
500
1000
1500
2000
Applied Pressure, PSIG

2/208

C. Static Testing (cont'd)			Initial Time and Date
4. Establish rated coolant flow and repeat Item C3. Be sure zero pressure output has stablized before proceeding. Seat transducer diaphragm. Computing identification 208-4.			
Ascending Output Voltage (mV)	Applied Pressure (psig)	Descending Output Voltage (mV)	12:30
.42	0	.41	8-5-69
1.91	100	1.91	
3.42	200	3.43	
4.91	300	4.96	
6.40	400	6.46	
7.90	500	7.96	
9.40	600	9.48	
10.86	700	11.00	
12.38	800	12.48	
13.90	900	14.00	
15.40	1000	15.55	
16.88	1100	17.00	
18.40	1200	18.50	
19.90	1300	20.00	
21.40	1400	21.50	
22.90	1500	23.00	
24.40	1600	24.49	
25.92	1700	26.00	
27.42	1800	27.44	
28.96	1900	28.98	
30.46	2000	30.46	

Ascending Pressure → Descending Pressure

NO. OF PTS.	IDENTIFICATION	SLOPE	Y-INTERCEPT	AVG. DEV
42	2Ø84	1.5Ø198Ø5E-Ø2	.42186147	4.3Ø94578E-Ø2


TRANSDUCER OUTPUT
VS
APPLIED PRESSURE
DYNISCO PT 311CA 2M
WET CALIBRATION
TRANSDUCER, OUTPUT, MilliVolts
0
5
10
15
20
25
30
0
500
1000
1500
2000
Applied Pressure, PSIG

C. Static Testing (cont'd)	Initial Time and Date
5. Duplicate Item C4 to determine repeatability. Seat transducer diaphragm. Computing identification 208-5.	8-8-64 1:00 PM

Ascending Output Voltage	Applied Pressure (psig)	Descending Output Voltage (mV)
.41	0	.40
1.91	100	1.93
3.41	200	3.45
4.92	300	4.97
6.42	400	6.48
7.91	500	7.98
9.42	600	9.50
10.89	700	11.00
12.38	800	12.51
13.87	900	14.01
15.38	1000	15.52
16.89	1100	17.01
18.40	1200	18.52
19.90	1300	20.01
21.46	1400	21.49
22.89	1500	22.99
24.40	1600	24.48
25.89	1700	25.89
27.38	1800	27.46
28.92	1900	28.95
30.43	2000	30.43

Ascending Pressure ↓ Descending Pressure ↑

NO. OF PTS.	IDENTIFICATION	SLOPE	Y-INTERCEPT	AVG. DEV.
42	2Ø85	1.4986298E-Ø2	.44584415	6.9863811E-Ø2

D. Dynamic Testing (cont'd)	Initial Time and Date

2. Shock Tube Testing

a. Install the transducer in accordance with instructions dated 2 June 1964 for coolant flow and static testing.
Transducer Location End mt. Diaphragm Position Flush

b. Establish coolant flow through the transducer and allow adequate warm-up time.

c. Insert a burst disc in the shock tube and proceed according to instructions dated 5 June 1964.
Test Gas N_2 Test Pressure 6.45 psia
Driver Gas He Burst Disk size 600 psi

d. Photograph the oscilloscope display with the Polaroid camera and record the following information

Date	Time	Picture No.	Vert. Sens.	Horiz. Sens.	Test Section Pressure psia	Burst Pressure psia
8/10/64		1	2 mv/cm	50 μs/cm	6.45	520
8/10/64		2	2 mv/cm	20 μs/cm	6.45	535

8/10/64 [illegible]

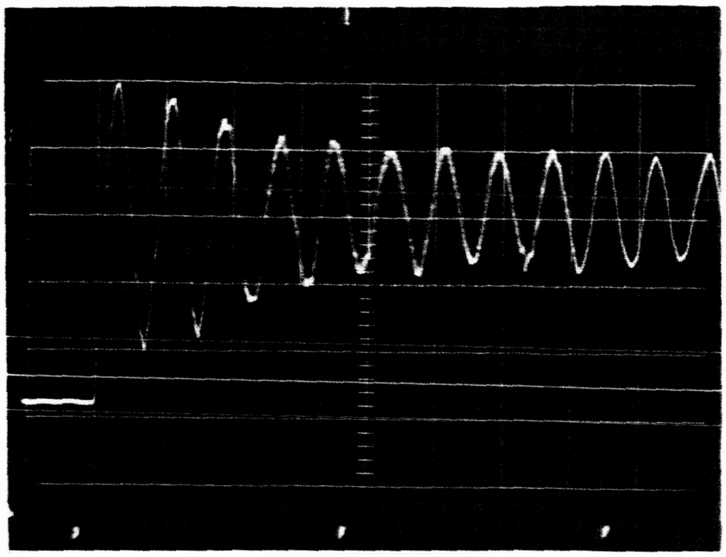
e. Insert ¼ inch thick steel plate between tube flanges ahead of transducer and repeat item d.

Date	Time	Picture No.	Vert. Sens.	Horiz. Sens.	Test Section Pressure psia	Burst Pressure psia
8/10/64		3	2 mv/cm	50 μs/cm	6.45	525
8/10/64		4	2 mv/cm	20 μs/cm	6.45	530

8/10/64 [illegible]

Other Data:

Dynamic Tests in Shock Tube



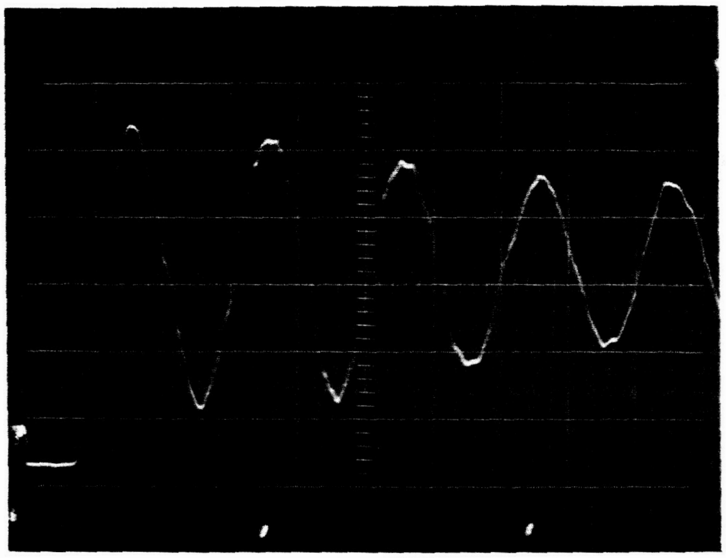
Picture No. 1

Vert. Sens. 2 mv/cm

Sweep Rate 50 µs/cm

Rise Time ____________

Nat'l Freq. ≃ 25000 cps



Picture No. 2

Vert. Sens. 2 mv/cm

Sweep Rate 20 µs/cm

Rise Time ____________

Nat'l Freq. ____________

Picture No. ____________

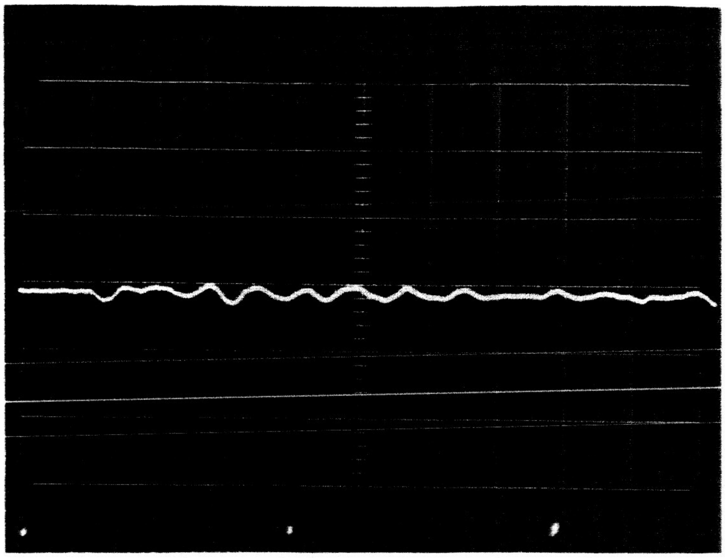
Vert. Sens. ____________

Sweep Rate ____________

Rise Time ____________

Nat'l Freq. ____________

Dynamic Tests in Shock Tube



Picture No. 3

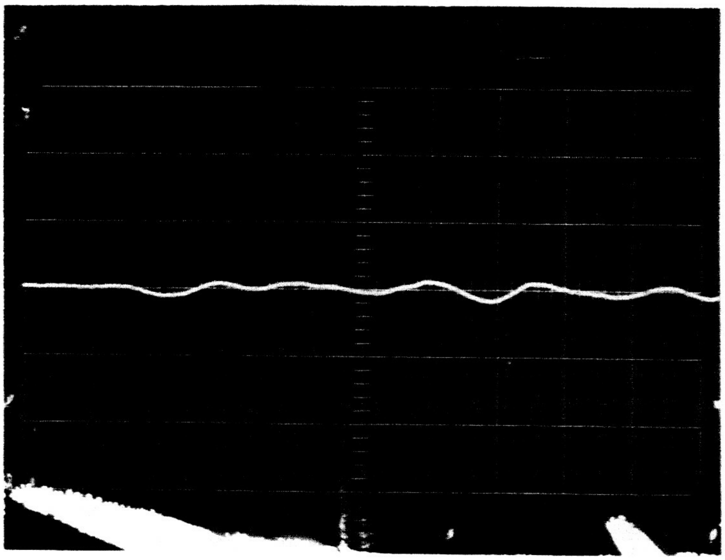
Vert. Sens. 2 mv/cm

Sweep Rate 50 μs/cm

Rise Time ____________

Nat'l Freq. ____________

(Blanked Shot corresponding to data of photo #1)



Picture No. 4

Vert. Sens. 2 mV/cm

Sweep Rate 20 μs/cm

Rise Time ____________

Nat'l Freq. ____________

(Blanked Shot Corresponing to data of photo # 2)

Picture No. ____________

Vert. Sens. ____________

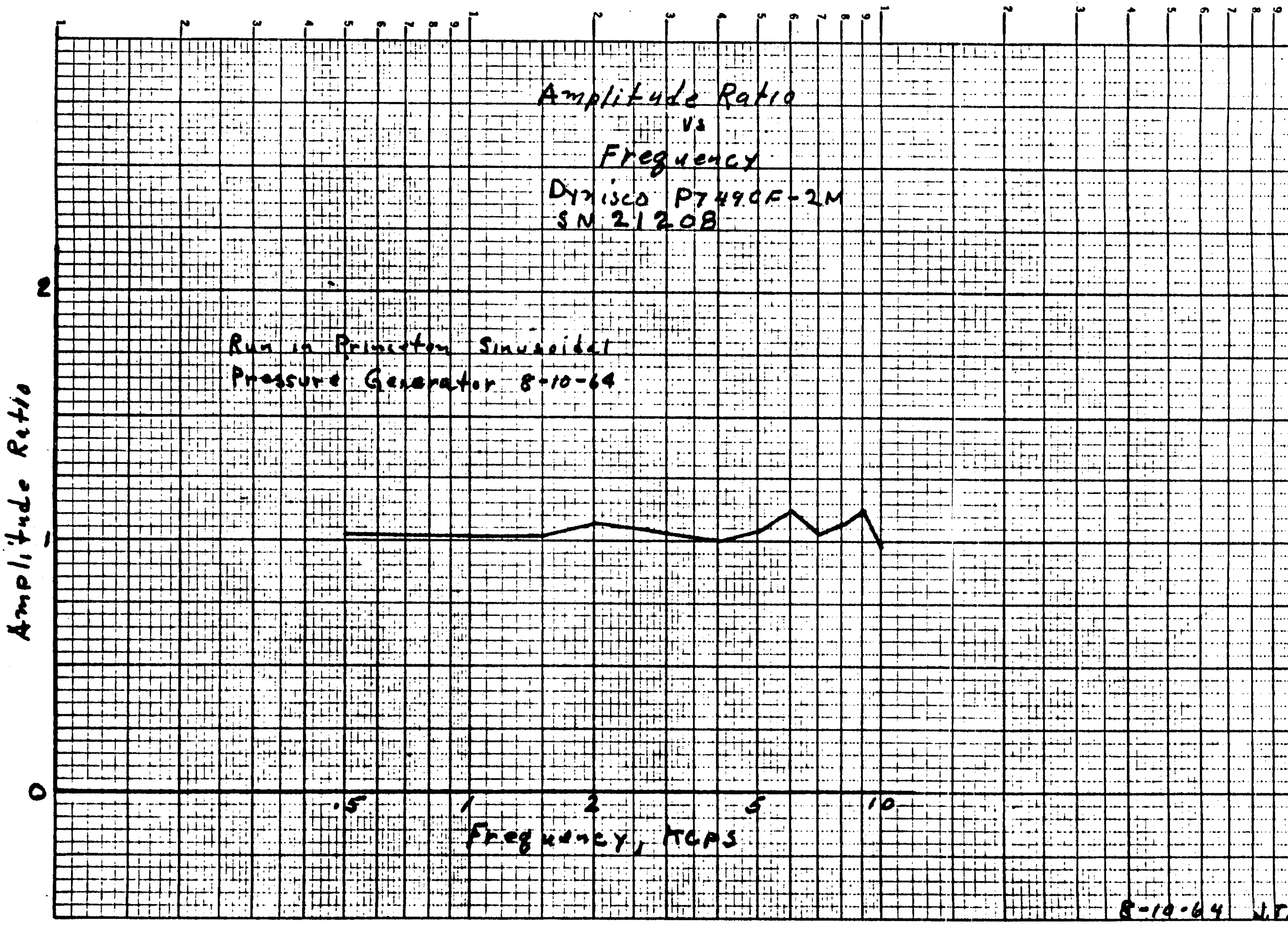
Sweep Rate ____________

Rise Time ____________

Nat'l Freq. ____________

D. Dynamic Testing (cont'd)	Initial Time and Date
3. Sinusoidal Pressure Generator a. Install the transducer in the generator chamber. Establish coolant flow and allow adequate warm up time. Chamber pressure 235 Diaphragm position Flush	8/10/64 [illegible]
b. At each excitation frequency record output level for each channel as indicated on the volt meter.	8/10/64 [illegible]

Frequency (kcps)	Monitor Output mv	Test Output mv
.5 K	950	88
1	420	49
1.5	300	35
2	220	27
3	155	18.5
4	130	15
5	102	12.3
6	85	11
7	78	9.3
8	67	8.2
9	60	7.8
10	56	6.3
12	53	7.1
14	45	6.6
16	36	5.5
18	34	7.2
20	33.5	8.2



Amplitude Ratio
vs
Frequency
Dynisco P749CF-2M
SN 21208
Run in Princeton Sinusoidal
Pressure Generator 8-10-64
Amplitude Ratio
0
1
2
.5
1
2
5
10
Frequency, MCPS
8-10-64 J.T.

E. Heat Transfer Testing	Initial Time and Date
1. Open Flame Test a. Install transducer in test apparatus and proceed according to instructions dated Diaphragm position Flush.	J.T. 8-10-64
b. Check coolant supply level.	
c. Ice cold junctions and check instrumentation.	
d. Establish coolant flow and allow adequate warm-up time.	
e. Prescribed operation conditions: Avg. coolant pressure, $\bar{p}_d$= 175 psig. ΔT instrument range 0.8 Transducer body temp. 3 =162° mv. Transducer position, D 3/4 in. Approximate heat flux ~~2~~ 1.5 BTU/in^{2}sec Ox gas 31 CFH, 40 psig Fuel gas 30 CFH 10 psig	
f. Get data points 1 and 2 below. Ignite torch and complete test. N. B. Hold coolant pressure throughout test.	

Date Point	Coolant Flow cps	Coolant T_{in} mv	Transducer Output mv	Zero Shift	Initial Time and Date
1 Coolant off	0	0.8	0.60		J.T. 8-10-64
2 Coolant on	121.6	0.8 ~~.42~~	0.42	-12 psig	
3 Heat on	121.6	0.8 ~~.32~~	0.32	-6.7 psi	
4 Both off	0	0.8	0.60		

Note: Attach ΔT trace to this form

Δt = 5.7°F
1.8 Btu/in² sec.

thermal Zero Shift = 3.72 psi/Btu in² sec.

Coolant Temp. rise = 3.16°F/Btu/in² sec

E. Heat Transfer Testing	Initial Time and Date
2. Open Flame Test a. Install transducer in test apparatus. Diaphragm position *Flush*.	J.T. 8-10-64
b. Check coolant supply level.	
c. Ice cold junctions and check instrumentation.	
d. Establish coolant flow and allow adequate warm-up time.	
e. Prescribed operation conditions: Avg. coolant pressure, $\bar{p}_d$= *175* psig. ΔT instrument range *0.8* Transducer body temp. *3* mv. *=162°* Transducer position, D *3/4* in. Approximate heat flux ~~4~~ *3* BTU/in^2sec Ox gas *85* CFH, *42* psig Fuel gas *65* CFH *12* psig	
f. Get data points 1 and 2 below. Ignite torch and complete test. N.B. Hold coolant pressure throughout test.	

Date Point	Coolant Flow cps	Coolant T_{in} mv	Transducer Output mv	*Zero Shift*	
1 Coolant off	0	0.8	0.60		
2 Coolant on	121.4	0.8	0.42	-12 psi	J.T.
3 Heat on	121.8	0.8	0.1	-21.35 psi	8-10-64
4 Both off	0	0.8	0.60		

Note: Attach ΔT trace to this form

Δt = 8.9°F
2.82 Btu/in²sec.

Thermal Zero Shift = 7.6 psi/Btu in²sec.

Coolant temp rise = 3.16°F/Btu/in²sec.

PRINCETON UNIVERSITY

DEPARTMENT OF AEROSPACE AND MECHANICAL SCIENCES

GUGGENHEIM LABORATORIES FOR THE AEROSPACE PROPULSION SCIENCES

FORM NO. 93e

JP-24 LABORATORY EVALUATION PROCEDURE FOR CURRENT WATER-COOLED FLUSH DIAPHRAGM TRANSIENT PRESSURE TRANSDUCERS

Type of Transducer: Four-Arm Strain Gage

Manufacturer: Dynisco Model: PT134-1.5M Serial: 22121

Other Data: Ceramic Coating (Alum. Oxide) on transducer body.

Requested by: ______ Conducted by: J.T., R.S., J.M.

Approved by: J.P.

Date Start: 6-17-65 Date Stop: 6-25-65

A. Inspection	Initial Time Date
1. Inspect transducer, especially for flaws or damage with a stereo-microscope and Zyglo as necessary, noting cracks, dents, imperfect welds, etc. (Attached photos or sketches as required). Diaphragm welded to transducer body. Machine tool marks on diaphragm	J.T. 6-17-65
2. Measure transducer for compliance with outline drawing. Note deviations: All dimensions within tolerance.	J.T. 6-17-65
3. Measure leakage resistance from all active pins to ground using the volt-ohmyst. Leakage resistance = ∞ megohm.	J.T. 6-17-65
4. For strain gage type transducers, measure resistances using the Wheatstone bridge. Input resistance = 362 ohms. Output resistance = 330 ohms.	J.T. 6-17-65

B. Coolant Testing	Initial Time Date

1. Install transducer in static test system in accordance with instructions dated 7 June '64 for coolant flow tests and static pressure calibrations. Use Δp- ΔT fittings, coolant inlet filter, coolant outlet sight-glass, and selected gaskets.

   N.B. These fittings are to remain on transducer throughout the evaluation. Connect transducer to instruments and auxiliary equipment. Follow manufacturer's procedures for the adjustment of auxiliary equipment and allow recommended warm-up time.

   Transducer gasket Flexitallic Adapter gasket Flexitallic

   Δp- ΔT Set No. 10 Max. Torque 100 in. lb.

Torque, in. lb.	0	100								
Output, mv	.75	.65								

   Auxiliary equipment, Serial No(s) and control settings ______

J.T. 6-17-65

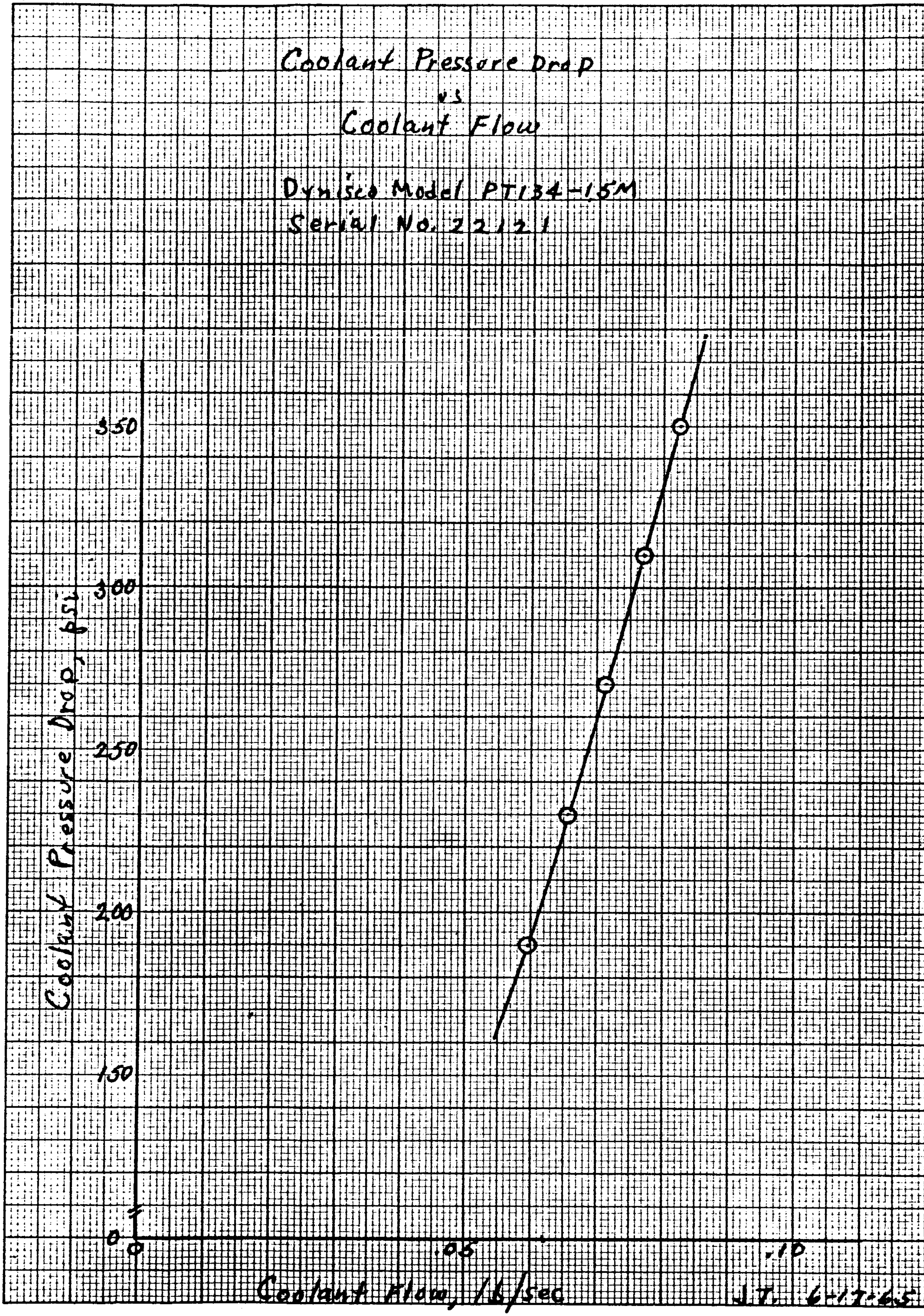
2. Attach coolant and instrumentation lines for coolant flow rate vs pressure drop test at rated average coolant pressure of 225 psig.

   Flow Meter Serial No. PQ NO. 3. Flow Meter Constant 1093

J.T. 6-17-65

P_{in} psig	P_{out} psig	Δp $P_{in}-P_{out}$	Coolant cps	Flow pps	Transducer Output mv	Transducer Output psig	Coolant Temperature mv	Coolant Temperature °F
0	0	0	0	0	+0.50	0	0.85	71
400	50	350	89.9	.0824	-0.04	27	"	"
380	70	310	84.1	.0771	-0.03	26.5	"	"
360	90	270	78.0	.0715	"	"	"	"
340	110	230	71.9	.0658	"	"	"	"
320	130	190	65.3	.0598	-0.02	26	"	"
0	0	0	0	0	+0.52	0	"	"

(Inlet established)


Coolant Pressure Drop
vs
Coolant Flow
Dynisco Model PT134-1.5M
Serial No. 22121
350
300
250
200
150
0
0
.05
.10
Coolant Pressure Drop, psi
Coolant Flow, lb/sec
J.T. 6-17-65

B. Coolant Testing

5. Repeat item 3.

P_{in} psig	P_{out} psig	ΔP $P_{in}-P_{out}$	Coolant cps	Flow pps	Transducer Output mv	psig	Coolant Temperature mv	°F
0	0	0	0	0				
0	0	0	0	0				

6. Disconnect signal lead and repeat item A3. Leakage resistance ∞. — J.T. 6-17-65

7. Connect signal lead and leave transducer energized. Report coolant test data.

8. Tag transducer for coolant conditions as follows: — J.T. 6-17-65
   a. Inlet Pressure 390 psig.
   b. Outlet Pressure 60 psig.
   c. Average Coolant Pressure 225 psig.
   d. Coolant Flowrate .08 lb./sec.
   e. Inlet tube as determined by items B2 and B4.

   N.B. All testing unless specifically directed otherwise, is to be carried out under the above conditions until the transducer is re-evaluated.

9. With coolant flowing observe zero reading during a one hour period at 5-minute intervals. Report any significant shift in zero.

Time of day	Output mv	Time of day	Output mv	Time of day	Output mv
10:15	+0.68	10:40	+0.68	11:00	+0.67
	"		"		0.66
	"		0.67		"
	"		"	11:15	"
10:35	"				

C. Static Testing	Initial Time and Date
1. Completely purge coolant passages of water with dry nitrogen gas from static test panel at 20 psig max. Leave coolant lines disconnected.	J.M. 6-21-65
2. Apply 2000 psig to transducer. Insert on appropriate voltage divider to bring output on the calibrator scale. Divider ratio = ———. Release applied pressure.	
3. Apply pressure in 100 psi steps to 2000 psig and return in equal steps to zero pressure. N. B. Care must be taken to approach each pressure in the particular direction of travel to avoid any masking of hysteresis or other effects. Computing Identification 1211.	J.M. 6-21-65

Ascending Pressure Output (mv)	Applied Pressure (psig)	Descending Pressure output (mv)
+0.66	0	+0.64
2.72	100	2.66
4.70	200	4.65
6.76	300	6.68
8.72	400	8.67
10.70	500	10.63
12.64	600	12.63
14.62	700	14.58
16.58	800	16.58
18.62	900	18.62
20.75	1000	20.54
22.57	1100	22.56
24.55	1200	24.53
26.56	1300	26.52
28.55	1400	28.52
30.49	1500	30.55
32.54	1600	32.51
34.48	1700	34.50
36.50	1800	36.48
38.47	1900	38.49
40.49	2000	40.49

Ascending Pressure ↓ / Descending Pressure ↑

NO. PTS.	ID	SLOPE	Y-INTERCEPT	AVE. DEV.
42	1211	.19882597E-01	.70549783E+00	.36514836E-01

C. Static Testing (cont'd)	Initial Time and Date
4. Establish rated coolant flow and repeat Item C3. Make certain that zero pressure output has stablized before proceeding. Seat transducer diaphragm. Computing identification 1212.	J.M. 6-21-65

Ascending Output Voltage (mV)	Applied Pressure (psig)	Descending Output Voltage (mV)
+0.08	0	+0.01
2.12	100	2.00
4.10	200	4.03
6.12	300	6.05
8.10	400	8.02
10.05	500	10.03
12.03	600	12.01
14.03	700	13.95
15.96	800	15.95
18.00	900	17.97
19.96	1000	19.95
21.92	1100	21.93
23.92	1200	23.93
25.93	1300	25.92
27.90	1400	27.90
29.89	1500	29.90
31.89	1600	31.88
33.86	1700	33.89
35.83	1800	35.85
37.83	1900	37.86
39.85	2000	39.85

Ascending Pressure ↓   Descending Pressure ↑

NO. PTS.	ID	SLOPE	Y-INTERCEPT	AVE. DEV.
42	1212	.19873701E-01	.84632034E-01	.25354627E-01

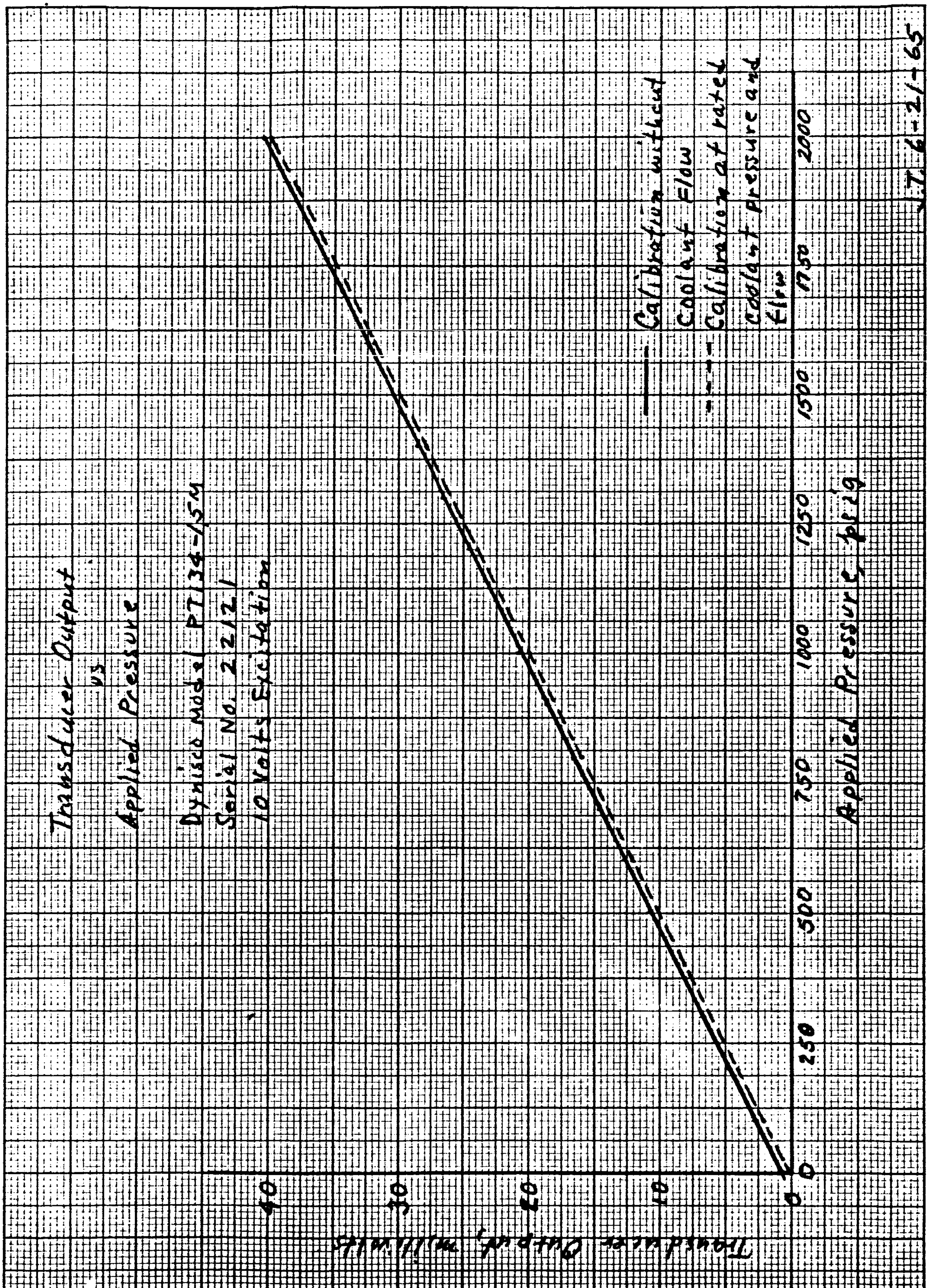
C. Static Testing (cont'd)	Initial Time and Date
5. Duplicate Item C4 to determine repeatability. Seat transducer diaphragm. Computing identification 1213.	JM 6-21-65

Ascending Output Voltage	Applied Pressure (psig)	Descending Output Voltage (mV)
+0.01	0	0.00
2.06	100	2.03
4.09	200	4.01
6.06	300	6.03
8.04	400	8.04
10.03	500	10.01
12.01	600	12.01
13.95	700	13.97
15.93	800	15.94
17.94	900	17.96
19.92	1000	19.94
21.89	1100	21.89
23.90	1200	23.92
25.89	1300	25.90
27.87	1400	27.94
29.85	1500	29.90
31.84	1600	31.87
33.83	1700	33.86
35.82	1800	35.85
37.82	1900	37.83
39.82	2000	39.82

Ascending Pressure

Descending Pressure

NO.PTS.	ID	SLOPE	Y-INTERCEPT	AVE. DEV.
42	1213	.19876493E-01	.58982683E-01	.21269248E-01



Transducer Output
vs
Applied Pressure
Dynisco Model PT134-15M
Serial No. 22121
10 Volts Excitation
Calibration without Coolant Flow
Calibration at rated coolant pressure and Flow
0
250
500
750
1000
1250
1500
1750
2000
Applied Pressure, psig
0
10
20
30
40
Transducer Output, millivolts
J.T. 6-21-65

D. Dynamic Testing (cont'd)	Initial Time and Date
2. Shock Tube Testing a. Install the transducer in accordance with instructions dated 2 June 1964 for coolant flow and static testing. Transducer Location End Mount Diaphragm Position Flush	6/23/65 F.S.
b. Establish coolant flow through the transducer and allow adequate warm-up time.	6/23/65 F.S.
c. Insert a burst disc in the shock tube and proceed according to instructions dated 5 June 1964. Test Gas N_2 Test Pressure 6.3 psia Driver Gas He Burst Disk size 500 psi	6/23/65 F.S.
d. Photograph the oscilloscope display with the Polaroid camera and record the following information	6/23/65 F.S.

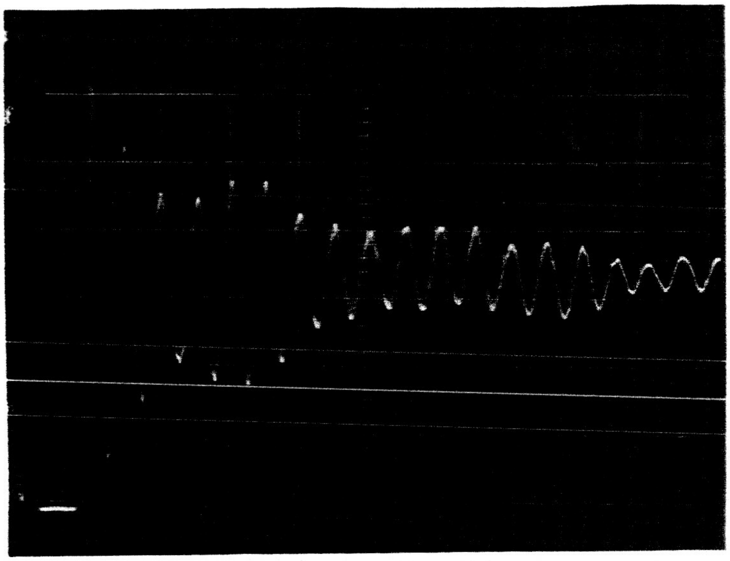
Date	Time	Picture No.	Vert. Sens.	Horiz. Sens.	Test Section Pressure psia	Burst Pressure psia
6/23/65		1	2.5 mv/cm	50 µs/cm	6.4	523
"		2	"	10 "	6.4	520

e. Insert $\frac{1}{4}$ inch thick steel plate between tube flanges ahead of transducer and repeat item d. — 6/23/65 F.S.

Date	Time	Picture No.	Vert. Sens.	Horiz. Sens.	Test Section Pressure psia	Burst Pressure psia
6/23/65		3	2.5 mv/cm	50 µs/cm	6.4	515
"		4	"	10 "	6.4	520

Other Data:

Dynamic Tests in Shock Tube



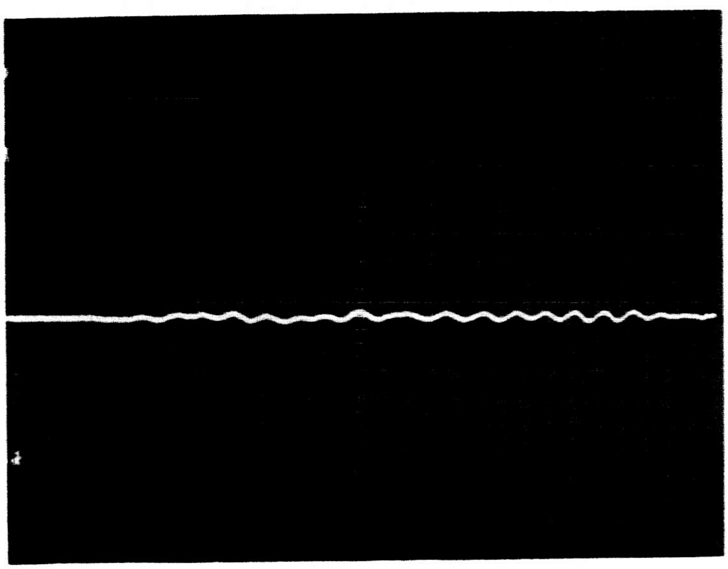
Picture No. 1

Vert. Sens. 2.5 mv/cm

Sweep Rate 50 μs/cm

Rise Time

Nat'l Freq. ≈ 39,500



Picture No. 3

Vert. Sens. 2.5 mv/cm

Sweep Rate 50 μs/cm

Rise Time

Nat'l Freq.

(Blank Slot)

Picture No.

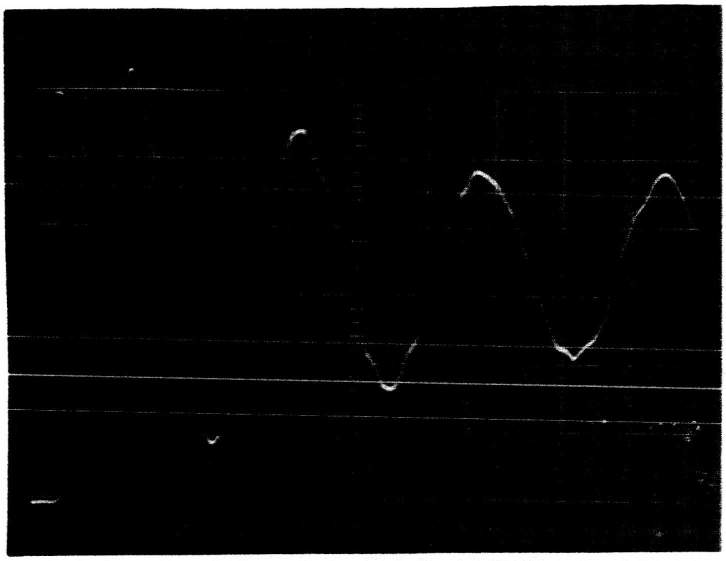
Vert. Sens.

Sweep Rate

Rise Time

Nat'l Freq.

Dynamic Tests in Shock Tube



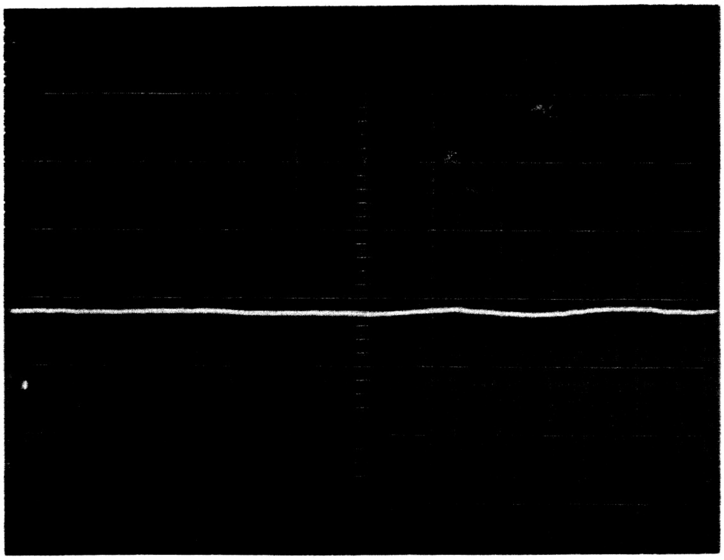
Picture No. 2

Vert. Sens. 2.5 mv/cm

Sweep Rate 10 μs/cm

Rise Time ≅ 5 μs

Nat'l Freq.



Picture No. 4

Vert. Sens. 2.5 mv/cm

Sweep Rate 10 μs/cm

Rise Time

Nat'l Freq.

(Blank Shot)

Picture No.

Vert. Sens.

Sweep Rate

Rise Time

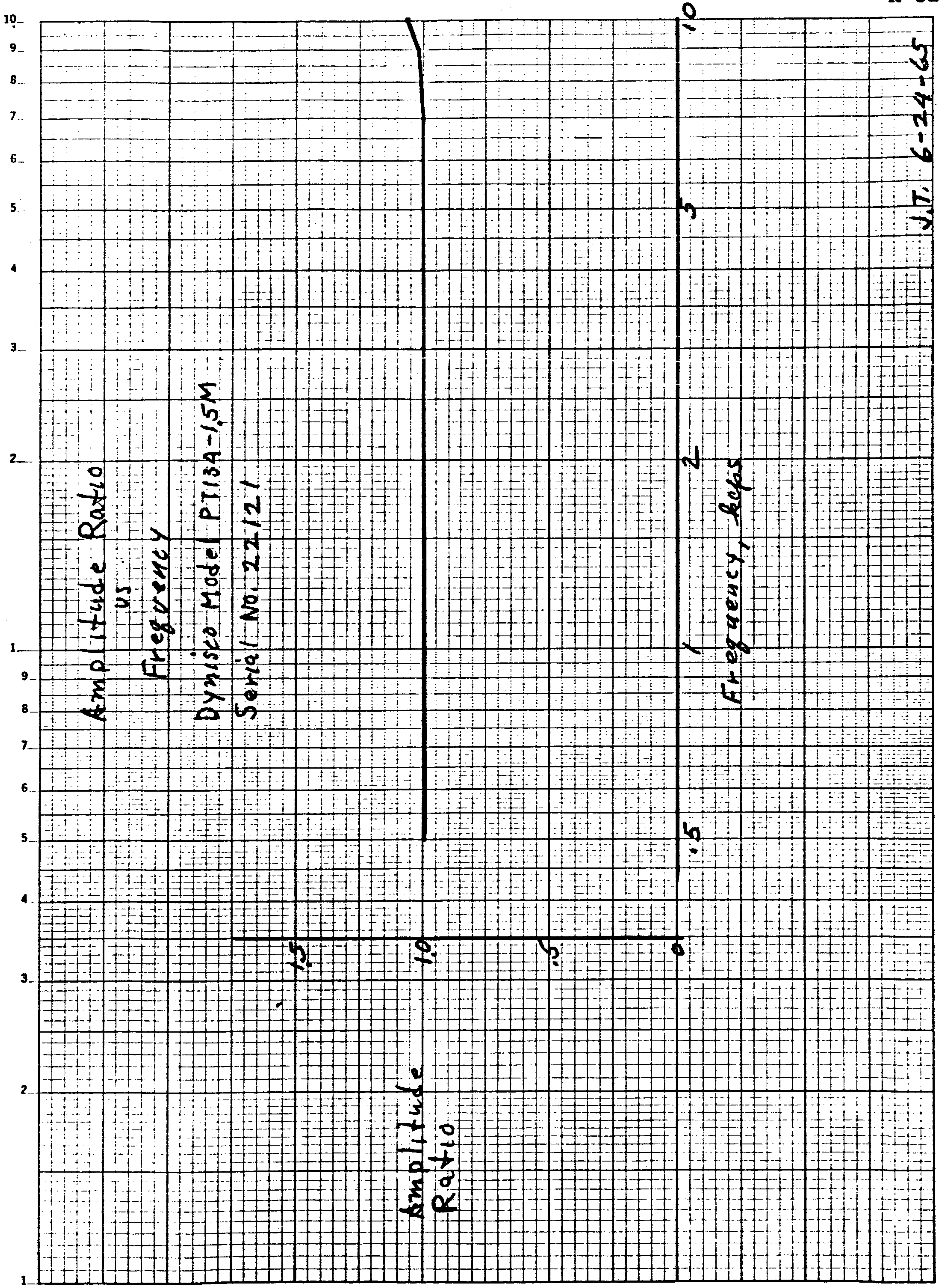
Nat'l Freq.

D. Dynamic Testing (cont'd)	Initial Time Date
3. Sinusoidal Pressure Generator a. Install the transducer in the generator chamber. Establish coolant flow and allow adequate warm up time. Plenim Pressure 1030 psig Chamber Pressure 250 psig Test Gas Helium Diaphragm Position Flush	J.T. 6-24-65
b. At 1000 cps, check peak to peak chamber pressure from output of monitor transducer and average chamber pressure from both test and monitor transducers. P_c, test 250 psig P_c, Mon. 250 psig pk-pk 89.2 psig	J.T. 6-24-65
c. At each excitation frequency record output level for each channel as indicated on the volt meter.	J.T. 6-24-65

Frequency (kcps)	Monitor Output mv	Test Output mv
.5	7900	752
1	6300	597.5
1.5	4750	450
2	3650	350
3	2600	250
4	1950	187.5
5	1640	157.5
6	1300	125
7	1175	112.5
8	1080	105
9	975	98
10	875	89

Test amplification = 95X

Monitor charge ampl. = 50 psi/volt



Amplitude Ratio
vs
Frequency
Dynisco Model PT13A-1.5M
Serial No. 22121
J.T. 6-24-65
Frequency, kcps
Amplitude Ratio
1.5
1.0
.5
0
.5
1
2
5
10

E. Heat Transfer Testing	Initial Time and Date
1. Open Flame Test a. Install transducer in test apparatus and proceed according to instructions dated ___ Diaphragm position Recessed 1/64"	J.M. 6-25-65
b. Check coolant supply level.	
c. Ice cold junctions and check instrumentation.	J.M.
d. Establish coolant flow and allow adequate warm-up time.	J.M.
e. Prescribed operation conditions: ΔT instrument range 0.4 mv. Transducer body temp. 3.6 mv. Transducer position, D 3/4 in. Approximate heat flux 1.5 $BTU/in^2 sec$ Ox gas 37 CFH, 40 psig Fuel gas 30 CFH 10 psig	
f. Get data points 1 and 2 below. Ignite torch and complete test. N. B. Hold coolant pressure throughout test.	

Data Point	Coolant Flow cps	Coolant T_{in} mv	Transducer Output mv	Transducer Output psi	Initial Time and Date
1 Coolant off			-0.54		J.M.
2 Coolant on	82.7	0.7	-0.81	-13.5	6-25-65
3 Heat on	82.5	0.7	-1.53	-36	
4 Both off			-0.60		

Note: Attach ΔT trace to this form

$q = 1.3$

$\frac{\Delta t}{q} = \frac{3.2}{1.3} = 2.46$

E. Heat Transfer Testing	Initial Time and Date
2. Open Flame Test a. Install transducer in test apparatus. Diaphragm position Recessed $\frac{1}{64}$	J.M. 6-25-65
b. Check coolant supply level.	
c. Ice cold junctions and check instrumentation.	
d. Establish coolant flow and allow adequate warm-up time.	
e. Prescribed operation conditions: Δ T instrument range 0.4 mv. Transducer body temp. 3.6 mv. Transducer position, D 3/4 in. Approximate heat flux 3 BTU/in^{2}sec Ox gas 92 CFH, 40 psig Fuel gas 60 CFH 10 psig	
f. Get data points 1 and 2 below. Ignite torch and complete test. N.B. Hold coolant pressure throughout test.	

Data Point	Coolant		Transducer Output		Initial Time and Date
	Flow cps	T_{in} mv	mv	psi	
1 Coolant off			-0.60		J.M.
2 Coolant on	82.4	0.7	-0.86	-13	6-25-65
3 Heat on	82.4	0.7	-1.82	-48	
4 Both off			-0.69		

Note: Attach ΔT trace to this form

$q = 1.63$

$\frac{\Delta t}{q} = \frac{4}{1.63} = 2.46$

PRINCETON UNIVERSITY

Department of Aerospace and Mechanical Sciences

Guggenheim Laboratories for the Aerospace Propulsion Sciences

FORM NO. 93e

JP-24 LABORATORY EVALUATION PROCEDURE FOR CURRENT WATER-COOLED FLUSH DIAPHRAGM

TRANSIENT PRESSURE TRANSDUCERS

Type of Transducer: Kistler 601A Miniature Quartz in Small passage Adaptor

Manufacturer: Aerojet General Corp. Model: HB4X-1 Serial: S/N 001

Other Data: 0.834 inch passage length

Requested by: MSFC Conducted by: J.T., R.S., M.M.

Approved by: J.T.

Date Start: 6-25-65 Date Stop: 6-30-65

A. Inspection	Initial Time Date
1. Inspect transducer, especially for flaws or damage with a stereo-microscope and Zyglo as necessary, noting cracks, dents, imperfect welds, etc. (Attached photos or sketches as required). Probe bent and damaged on end.	6-25-65 J.T.
2. Measure transducer for compliance with outline drawing. Note deviations: ______	
3. Measure leakage resistance from all active pins to ground using the volt-ohmyst. Leakage resistance = ∞ megohm. Charge Decay = 1 volt/10 min at 92 V input	6-25-65 J.T.
4. For strain gage type transducers, measure resistances using the Wheatstone bridge. Input resistance = ______ ohms. Output resistance = ______ ohms.	

B. Coolant Testing	Initial Time Date

1. Install transducer in static test system in accordance with instructions dated 2 June '64 for coolant flow tests and static pressure calibrations. Use Δp- ΔT fittings, coolant inlet filter, coolant outlet sight-glass, and selected gaskets.

N.B. These fittings are to remain on transducer throughout the evaluation. Connect transducer to instruments and auxiliary equipment. Follow manufacturer's procedures for the adjustment of auxiliary equipment and allow recommended warm-up time.

Transducer gasket Teflon Adapter gasket Flexitallic

Δp- ΔT Set No. —— Max. Torque 60 in. lb.

Torque, in. lb.	0	10	20	30	40	50	60	70	80	90
Output, ~~mv~~ V	.073						.073			

Auxiliary equipment, Serial No(s) and control settings

Kistler Chg Amp. Mod 566 S/N 406. Set 5 mv/psi

Princeton Applied Research Digital Voltmeter Model CS-3.1

S/N 905, Set Auto

2. Attach coolant and instrumentation lines for coolant flow rate vs pressure drop test at rated average coolant pressure of ______ psig.

Flow Meter Serial No. ______. Flow Meter Constant ______

P_{in} psig	P_{out} psig	ΔP $P_{in}-P_{out}$	Coolant cps	Flow pps	Transducer Output mv	Transducer Output psig	Coolant Temperature mv	Coolant Temperature °F
0	0	0	0	0				
0	0	0	0	0				

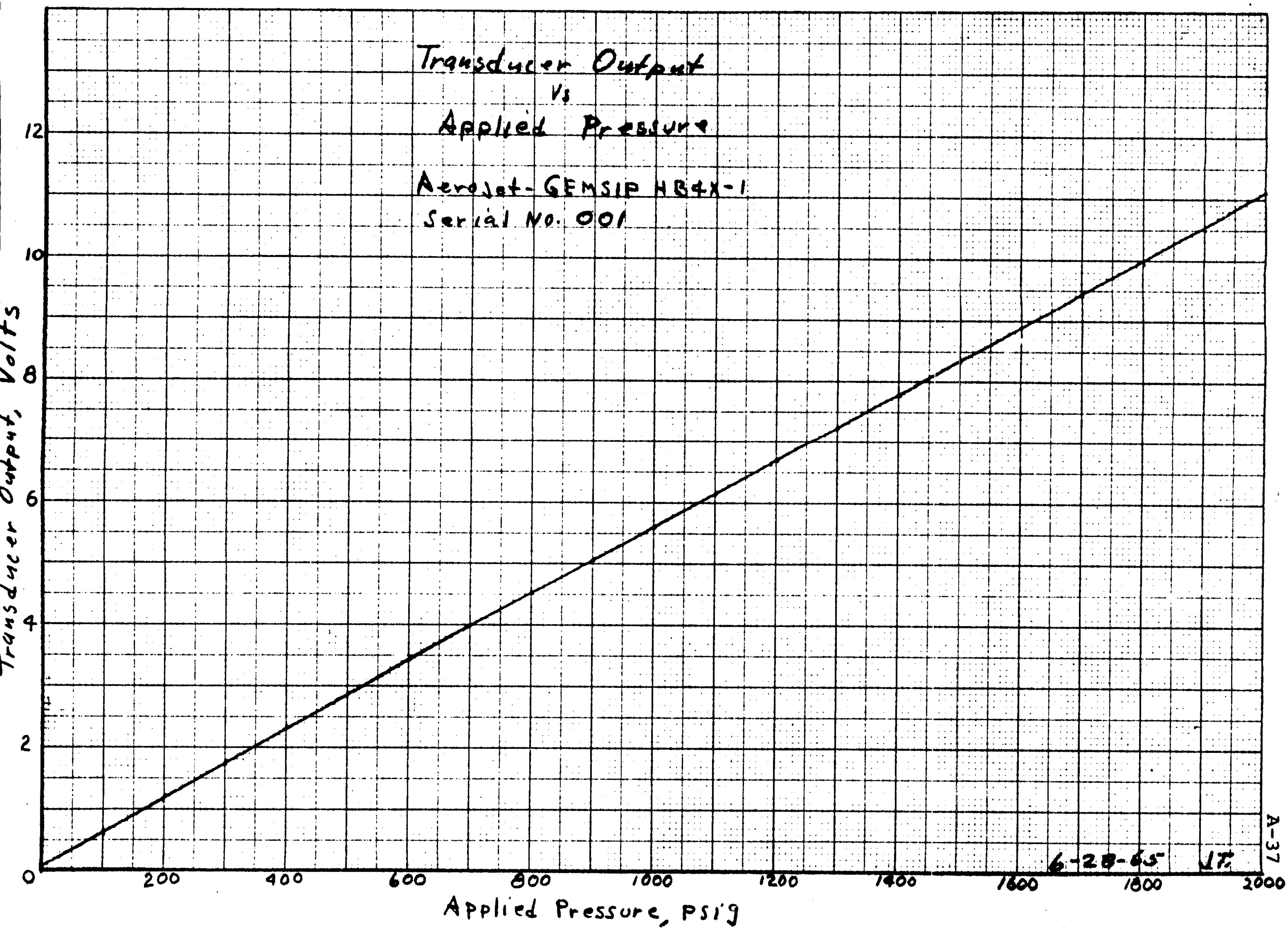
C. Static Testing	Initial Time and Date
1. Completely purge coolant passages of water with dry nitrogen gas from static test panel at 20 psig max. Leave coolant lines disconnected.	
2. Apply 2000 psig to transducer. Insert on appropriate voltage divider to bring output on the calibrator scale. Divider ratio = None. Release applied pressure.	
3. Apply pressure in ______ psi steps to ____ psig and return in equal steps to zero pressure. N. B. Care must be taken to approact each pressure in the particular direction of travel to avoid any masking of hysteresis or other effects. Computing identification 0011.	

Ascending Pressure Output (mv)	Applied Pressure (psig)	Descending Pressure output (mv)
.073	0	.034
.640	100	.591
1.22	201 198	1.16
1.79	302	1.75
2.34	400	2.31
2.89	500	2.87
3.44	600	3.44
3.98	700	3.97
4.52	800	4.51
5.06	900	5.04
5.61	1000	5.59
6.14	1100	6.14
6.70	1200 1190	6.63
7.23	1300	7.23
7.79	1400	7.78
8.32	1500	8.32
8.87	1600	8.87
9.41	1700	9.42
9.95	1800	10.00
10.50	1900	10.50
11.10	2000	11.10

Ascending Pressure ↓ Descending Pressure ↑

$$\left(\frac{5.485\times10^{-3}\,V}{psi}\right)\left(\frac{pCb}{5\times10^{-3}\,V}\right) = 1.097\ \frac{pCb}{psi}$$

NO.PTS.	ID	SLOPE	Y-INTERCEPT	AVE. DEV.
42	11	.54848811E-02	.10717456E+00	.26367367E-01


Transducer Output
Vs
Applied Pressure
Aerojet-GEMSIP HB4X-1
Serial No. 001
Transducer Output, Volts
0
2
4
6
8
10
12
Applied Pressure, PSIG
200
400
600
800
1000
1200
1400
1600
1800
2000
6-28-65 JT.

D. Dynamic Testing (cont'd)	Initial Time and Date
2. Shock Tube Testing a. Install the transducer in accordance with instructions dated 2 June 1964 for coolant flow and static testing. Transducer Location End Diaphragm Position Flush	6-29-65 R.E.S.
b. Establish coolant flow through the transducer and allow adequate warm-up time.	—
c. Insert a burst disc in the shock tube and proceed according to instructions dated 5 June 1964. Test Gas N_2 Test Pressure ≈ 6.3 psia Driver Gas He Burst Disk size ≈ 540 psi	
d. Photograph the oscilloscope display with the Polaroid camera and record the following information	6-29-65 R.E.S.

Date	Time	Picture No.	Vert. Sens.	Horiz. Sens.	Test Section Pressure psia	Burst Pressure psia
6-29-65		1	555 mV/cm	50 µs/cm	6	534 (He Bleed)
"		2	"	"	6.3	537 (Blank)
"		3	"	100	6.3	545 (no Bleed)
"		4	"	"	6.0	537 (He Bleed)
"		5	"	"	6.3	535 (Blank)

e. Insert ¼ inch thick steel plate between tube flanges ahead of transducer and repeat item d.

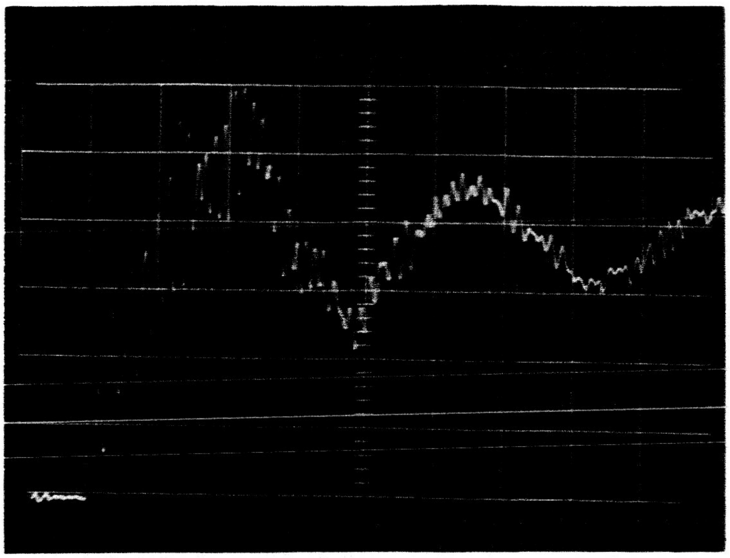
Date	Time	Picture No.	Vert. Sens.	Horiz. Sens.	Test Section Pressure psia	Burst Pressure psia

Other Data:

Helium Bleed set at 880 psig for Shots 1 & 4

Charge amplifier Model 566, SN 406 Set 10 mm/pcb

Dynamic Tests in Shock Tube



Picture No. 1

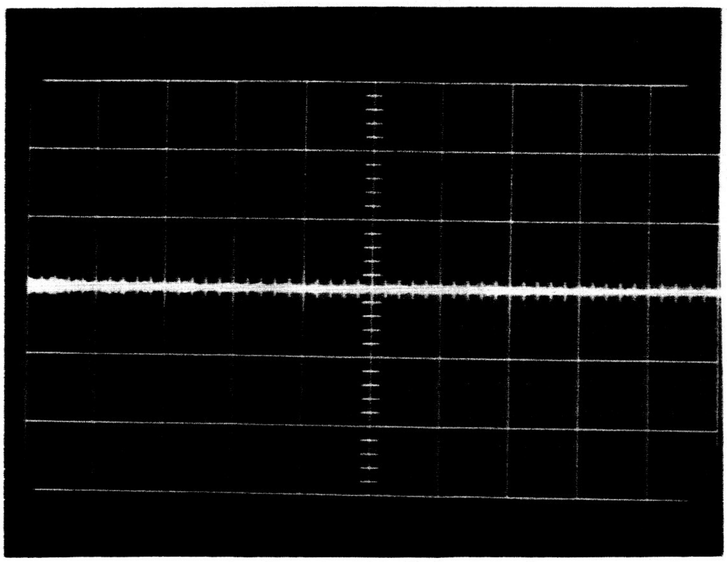
Vert. Sens. 555 mV/cm

Sweep Rate 50 μs/cm

Rise Time ≈ 50 μs

Nat'l Freq.

(He Bleed)



Picture No. 2

Vert. Sens. 555 mV/cm

Sweep Rate 50 μs/cm

Rise Time (Acceleration Test)

Nat'l Freq.

Picture No.

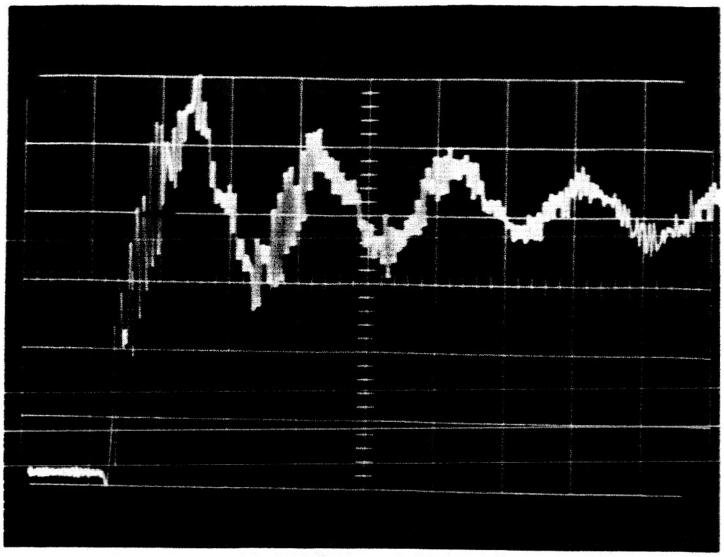
Vert. Sens.

Sweep Rate

Rise Time

Nat'l Freq.

Dynamic Tests in Shock Tube



Picture No. 3

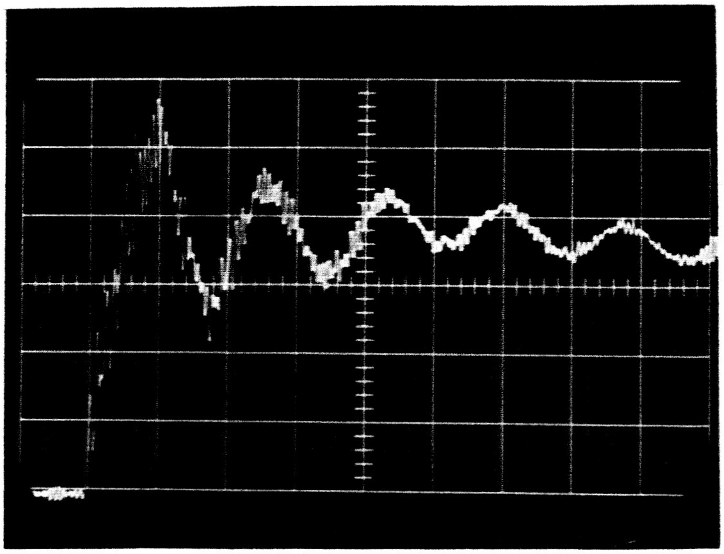
Vert. Sens. 555 mv/cm

Sweep Rate 100 μs/cm

Rise Time ≈ 50 μs

Nat'l Freq. ≈ 5340 cps

(No He Bleed)



Picture No. 4

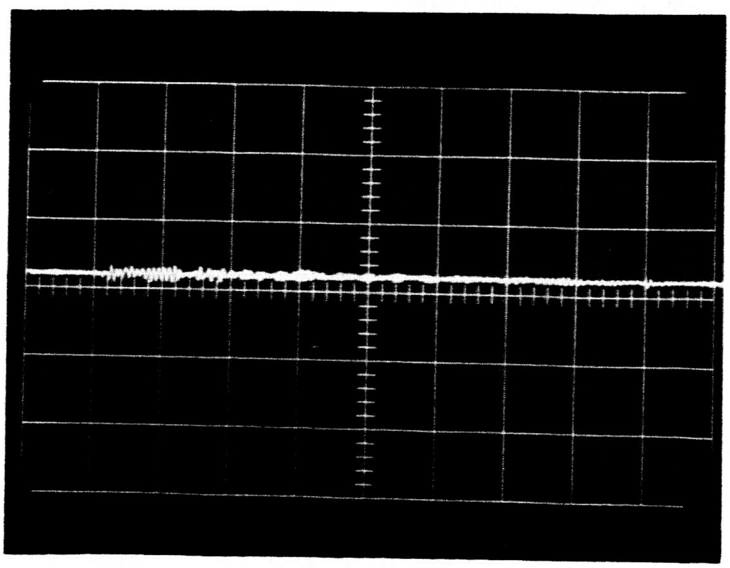
Vert. Sens. 555 mv/cm

Sweep Rate 100 μs/cm

Rise Time ≈ 50 μs

Nat'l Freq. ≈ 5875 cps

(He Bleed)



Picture No. 5

Vert. Sens. 555 mv/cm

Sweep Rate 100 μs/cm

Rise Time (Acceleration Test)

Nat'l Freq. ______________

D. Dynamic Testing (cont'd)	Initial Time Date
3. Sinusoidal Pressure Generator a. Install the transducer in the generator chamber. Establish coolant flow and allow adequate warm up time. Plenim Pressure 1030 psig Chamber Pressure 250 psig Test Gas Helium Diaphragm Position Flush	J.T. 6-30-65
b. At 1000 cps, check peak to peak chamber pressure from output of monitor transducer. and average chamber pressure from both test and monitor transducers. P_c, test 250 psig P_c, Mon. 250 psig pk-pk 147 psig	
c. At each excitation frequency record output level for each channel as indicated on the volt meter.	J.T. 6-30-65

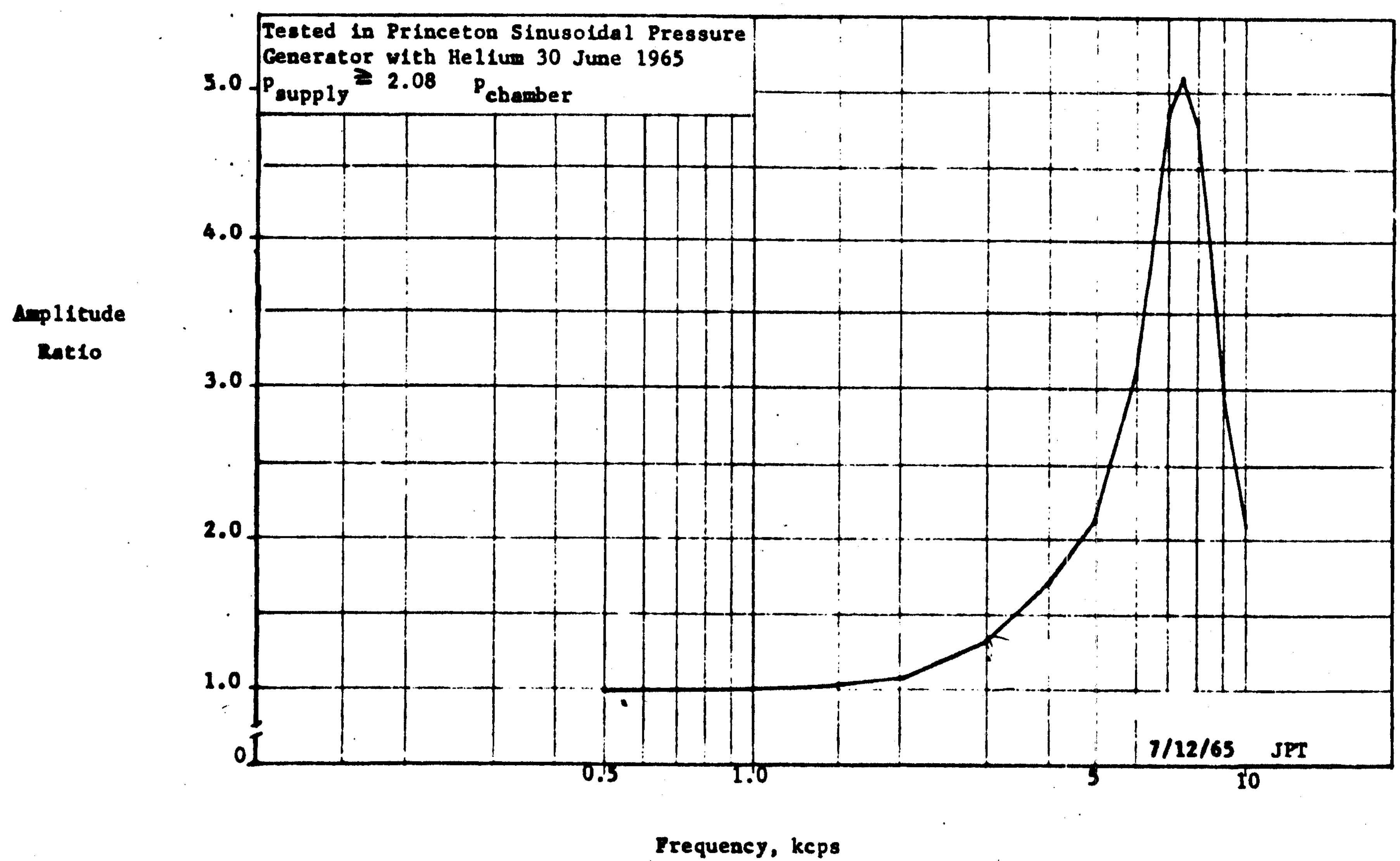
Frequency (kcps)	Monitor Output mv	Test Output mv
0.5	7500	7350
1.0	5700	5700
1.5	4150	4250
2.0	3200	3450
3.0	2220	2920
4.0	1600	2720
5.0	1300	2800
6.0	1100	3400
7.0	1000	4820
8.0	1000	4800
9.0	935	2850
10.0	860	1775
7.5	1000	5100

PRINCETON UNIVERSITY
Department of Aerospace and Mechanical Sciences
Guggenheim Laboratories for the Aerospace Propulsion Sciences

JP24 TRANSIENT PRESSURE MEASURING METHODS RESEARCH

Amplitude Ratio vs. Frequency

Aerojet GEMSIP HB4X-1



PRINCETON UNIVERSITY
DEPARTMENT OF AEROSPACE AND MECHANICAL SCIENCES
GUGGENHEIM LABORATORIES FOR THE AEROSPACE PROPULSION SCIENCES

FORM NO. 93e

JP-24 LABORATORY EVALUATION PROCEDURE FOR CURRENT WATER-COOLED FLUSH DIAPHRAGM TRANSIENT PRESSURE TRANSDUCERS

Type of Transducer: Piezoelectric, Miniature Quartz

Manufacturer: Kistler Instrument Co. Model: 616 H Serial: 107

Other Data: 601A Transducer, S/N 14967

Requested by: ______ Conducted by: F.E.d. & J.T.

Approved by: J.T.

Date Start: 6/28/65 Date Stop: 6/30/65

A. Inspection	Initial Time Date
1. Inspect transducer, especially for flaws or damage with a stereo-microscope and Zyglo as necessary, noting cracks, dents, imperfect welds, etc. (Attached photos or sketches as required).	J.T. 6-28-65
2. Measure transducer for compliance with outline drawing. Note deviations:	J.T. 6-28-65
3. Measure leakage resistance from all active pins to ground using the volt-ohmyst. Leakage resistance = ∞ megohm. Charge Decay @ 150V input = 1.6V/min	J.T. 6-28-65
4. For strain gage type transducers, measure resistances using the Wheatstone bridge. Input resistance = ______ ohms. Output resistance = ______ ohms.	

B. Coolant Testing	Initial Time Date
1. Install transducer in static test system in accordance with instructions dated 2 June '64 for coolant flow tests and static pressure calibrations. Use Δp- ΔT fittings, coolant inlet filter, coolant outlet sight-glass, and selected gaskets.	7.E.S.
N.B. These fittings are to remain on transducer throughout the evaluation. Connect transducer to instruments and auxiliary equipment. Follow manufacturer's procedures for the adjustment of auxiliary equipment and allow recommended warm-up time.	6-28-65

Transducer gasket Copper Adapter gasket Flexitallic

Δp- ΔT Set No. 14 Max. Torque 100 in. lb.

Torque, in. lb.	0									
Output, mv										

Auxiliary equipment, Serial No(s) and control settings

Kistler Model 504 Chg Amp S/N 503, 500 psi/V, Sens. 1.08

PAR Model CS-3.1 Digital Voltmeter S/N 905-Set on Auto.

2. Attach coolant and instrumentation lines for coolant flow rate vs pressure drop test at rated average coolant pressure of 1000 psig. — 6-28-65

Flow Meter Serial No. 3/16-3. Flow Meter Constant 1093

P_{in} psig	P_{out} psig	ΔP $P_{in}-P_{out}$	Coolant Flow cps	pps	Transducer Output mv	psig	Coolant Temperature mv	°F
0	0	0	0	0	.966		0.85	71
1100	900	200	260.0	0.2380	.970		"	"
1075	925	150	233.3	0.2135	.974		"	"
1050	950	100	195.2	0.1788	.976		"	"
1025	975	50	143.6	0.1313	.978		"	"
0	0	0	0	0				

3.

B. Coolant Testing	Initial Time Date

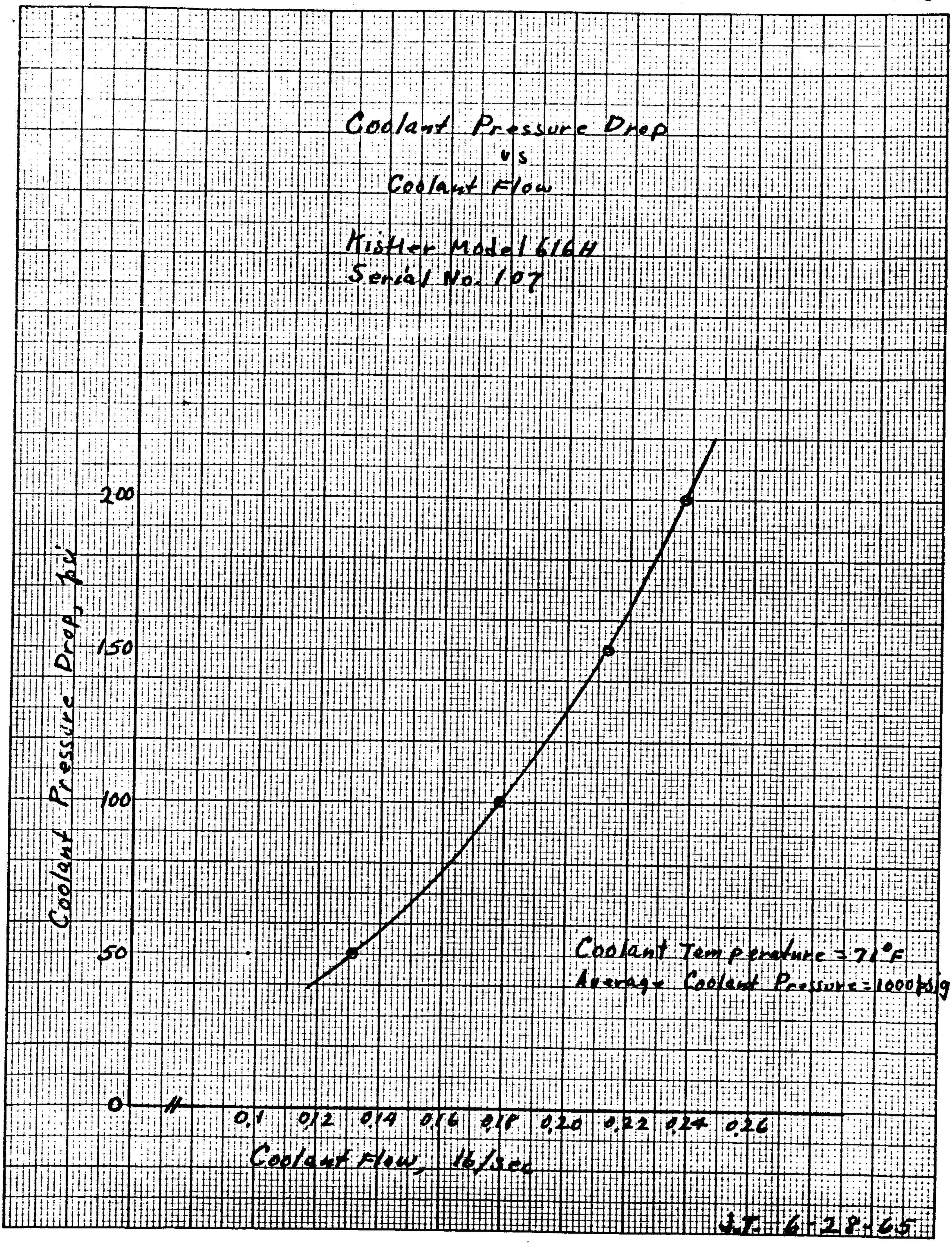
3. ~~Apply one-half rated pressure on diaphragm and repeat item 2.~~

P_{in} psig	P_{out} psig	ΔP $P_{in}-P_{out}$	Coolant cps	Flow pps	Transducer Output mv	Transducer Output psig	Coolant Temperature mv	Coolant Temperature °F
0	0	0	0	0				
0	0	0	0	0				

4. Reverse coolant flow by changing Δp- ΔT fittings at transducer. Repeat item 2.

P_{in} psig	P_{out} psig	ΔP $P_{in}-P_{out}$	Coolant cps	Flow pps	Transducer Output mv	Transducer Output psig	Coolant Temperature mv	Coolant Temperature °F
0	0	0	0	0				
1025	975	50	143.5					
1075	925	150	233.4					
0	0	0	0	0				

J.T.
6-28-65
(No Change in Flow)


Coolant Pressure Drop
vs
Coolant Flow
Kistler Model 616H
Serial No. 107
Coolant Pressure Drop, psi
200
150
100
50
0
0.1
0.12
0.14
0.16
0.18
0.20
0.22
0.24
0.26
Coolant Flow, lb/sec
Coolant Temperature = 71°F
Average Coolant Pressure = 1000 psig
J.T. 6-28-65

B. Coolant Testing

5. Repeat item 3.

P_{in} psig	P_{out} psig	ΔP $P_{in}-P_{out}$	Coolant cps	Flow pps	Transducer Output mv	psig	Coolant Temperature mv	°F
0	0	0	0	0				
0	0	0	0	0				

6. Disconnect signal lead and repeat item A3. Leakage resistance ________________.

7. Connect signal lead and leave transducer energized. Report coolant test data.

8. Tag transducer for coolant conditions as follows: 6-28-65 J.T.

   a. Inlet Pressure 1025 psig.

   b. Outlet Pressure 975 psig.

   c. Average Coolant Pressure 1000 psig.

   d. Coolant Flowrate 0.131 lb./sec.

   e. Inlet tube as determined by items B2 and B4.

   N.B. All testing unless specifically directed otherwise, is to be carried out under the above conditions until the transducer is re-evaluated.

9. With coolant flowing observe zero reading during a one hour period at 5-minute intervals. Report any significant shift in zero. 6-28-65 J.T.

Time of day	Output ~~mv~~ V	Time of day	Output ~~mv~~ V	Time of day	Output ~~mv~~ V
2:20	0.976	2:40	1.11	3:00	1.14
	1.02		1.13		1.14
	1.05		1.13		1.15
	1.08		1.14	3:15	1.15

E. Static Testing	Initial Time and Date
1. Completely purge coolant passages of water with dry nitrogen gas from static test panel at 20 psig max. Leave coolant lines disconnected.	6/28/65 JCS
2. Apply 2,000 psig to transducer. Insert on appropriate voltage divider to bring output on the calibrator scale. Divider ratio = 0. Release applied pressure.	
3. Apply pressure in 100 psi steps to 2000 psig and return in equal steps to zero pressure. N. B. Care must be taken to approach each pressure in the particular direction of travel to avoid any masking of hysteresis or other effects. Computing identification 6161.	6/2 JS

Ascending Pressure Output ~~(mv)~~ (V)	Applied Pressure (psig)	Descending Pressure output ~~(mv)~~ (V)
.856	0	.821
1.06	1	1.03
1.26	2	1.24
1.47	3	1.45
1.67	4	1.65
1.87	5	1.85
2.08	6	2.06
2.28	7	2.26
2.49	800	2.47
2.69	900	2.67
2.90	1000	2.88
3.11	1100	3.09
3.32	1200	3.29
3.52	1300	3.49
3.73	1400	3.70
3.93	1500	3.90
4.14	1600	4.10
4.35	1700	4.30
4.55	1800	4.50
4.76	1900	4.70
4.97	2000	4.97

Ascending Pressure → Descending Pressure

AVE. DEV. .16625434E-01

Y-INTERCEPT .83754761E+00

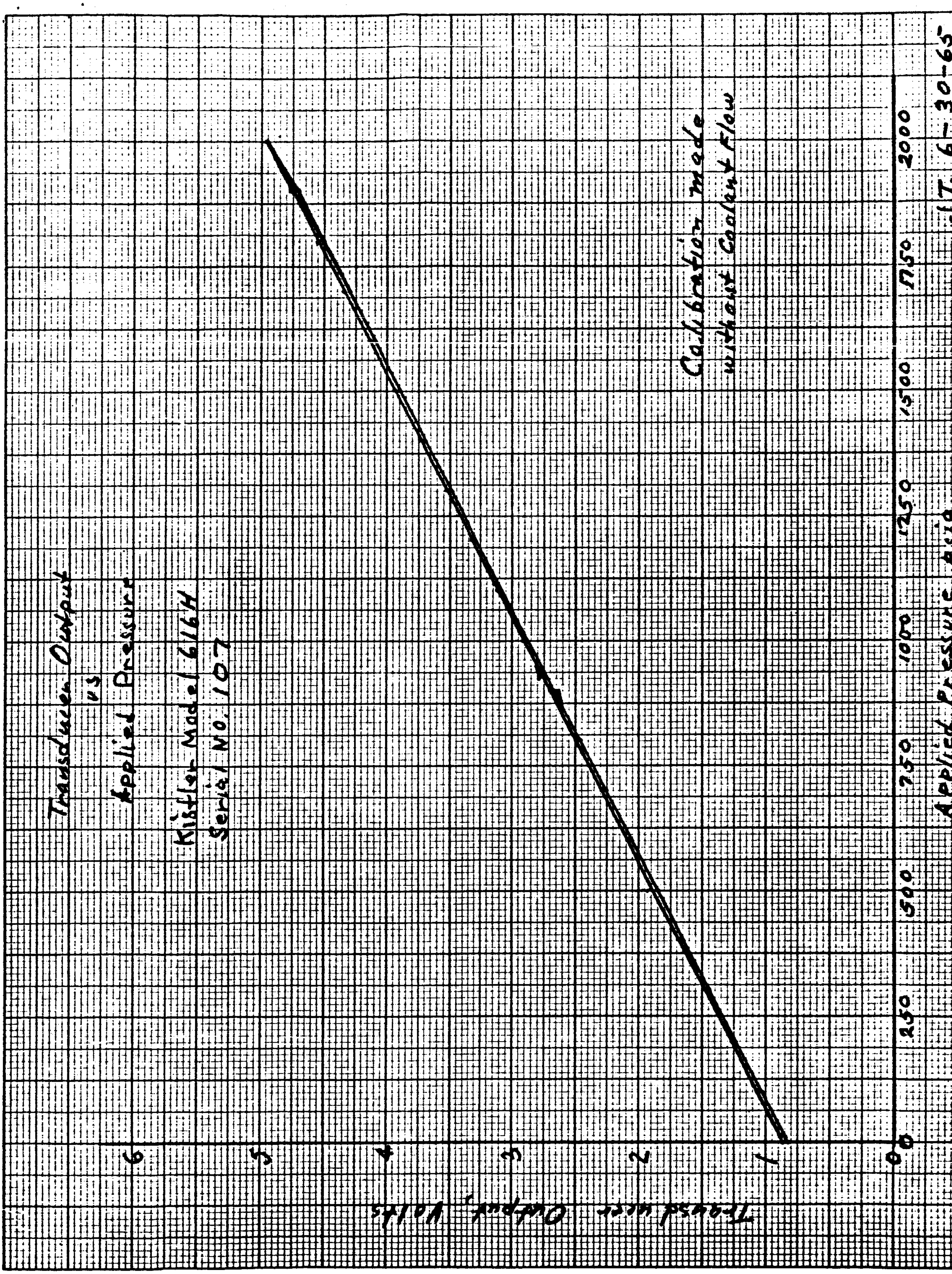
SLOPE .20535714E-02

ID 6161

NO. PTS. 42

N.B. Report apparent erroneous data before proceeding with evaluation.

540 Chg Amp S/N 503 Setting 500 psi/v. Sens. 1.08


Transducer Output
vs
Applied Pressure
Kistler Model 616H
Serial No. 107
Calibration made
without Coolant Flow
Applied Pressure, psig
0
250
500
750
1000
1250
1500
1750
2000
Transducer Output, Volts
1
2
3
4
5
6
J.T. 6-30-65

C. Static Testing (cont'd)	Initial Time and Date
4. Establish rated coolant flow and repeat Item C3. **Make certain** that zero pressure output has stablized before proceeding. Seat transducer diaphragm. Computing identification 6162.	6/28/65 J.T.

Ascending Output Voltage (~~mV~~V)	Applied Pressure (psig)	Descending Output Voltage (~~mV~~V)
0.977	0	1.02
1.180	100	1.23
1.39	200	1.43
1.59	300	1.64
1.79	400	1.85
2.20	600	2.25
2.62	800	2.66
3.03	1000	3.08
3.44	1200	3.48
3.86	1400	3.89
4.27	1600	4.29
4.67	1800	4.69
4.88	1900	4.89
5.09	2000	5.09

Ascending Pressure ↓ — Descending Pressure ↑

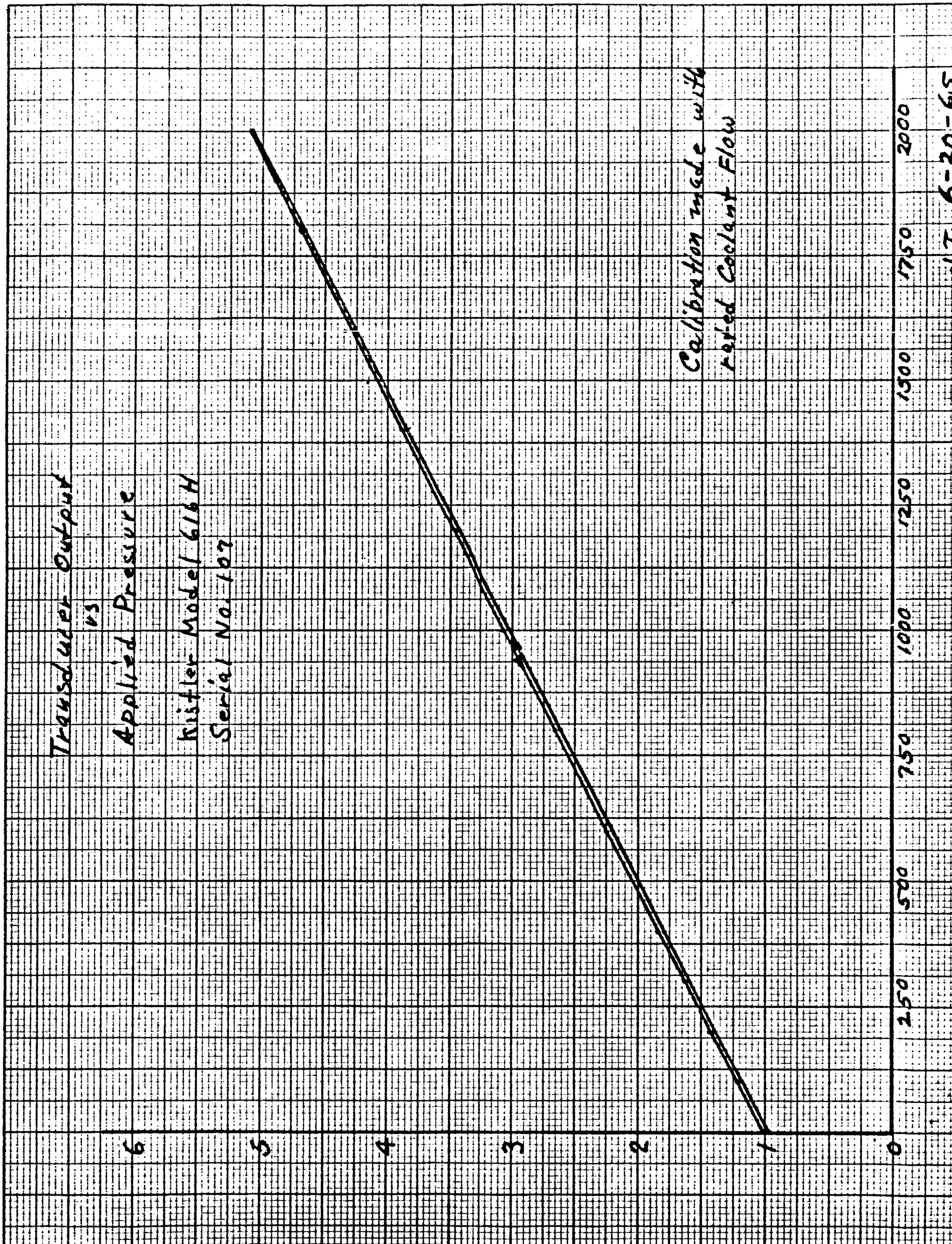
NO.PTS.	ID	SLOPE	Y-INTERCEPT	AVE. DEV.
28	6162	.20464749E-02	.10014558E+01	.20310096E-01

C. Static Testing (cont'd)	Initial Time and Date
5. Duplicate Item C4 to determine repeatability. Seat transducer diaphragm. Computing identification 6163.	6/28/65 J.P.

Ascending Output Voltage (V)	Applied Pressure (psig)	Descending Output Voltage (V)
0.978	0	1.01
1.180	100	1.22
1.37	200	1.42
1.58	300	1.63
1.79	400	1.83
2.20	600	2.25
2.61	800	2.65
3.02	1000	3.06
3.43	1200	3.47
3.84	1400	3.87
4.26	1600	4.29
4.66	1800	4.69
4.87	1900	4.88
5.08	2000	5.08

Ascending Pressure ↓ / Descending Pressure ↑

NO. PTS.	ID	SLOPE	Y-INTERCEPT	AVE. DEV.
28	6163	.20454749E-02	.99315581E+00	.19001879E-01


Transducer Output
vs
Applied Pressure
Kistler Model 616H
Serial No. 107
Calibration made with
rated Coolant Flow
J.T. 6-30-65
0
1
2
3
4
5
6
250
500
750
1000
1250
1500
1750
2000

D. Dynamic Testing (cont'd)	Initial Time and Date
2. Shock Tube Testing a. Install the transducer in accordance with instructions dated 2 June 1964 for coolant flow and static testing. Transducer Location End Diaphragm Position Flush	RES. 6-29-65
b. Establish coolant flow through the transducer and allow adequate warm-up time.	RES. 6-29-65
c. Insert a burst disc in the shock tube and proceed according to instructions dated 5 June 1964. Test Gas N_2 Test Pressure 6.3 psia Driver Gas He Burst Disk size 540 psi	

d. Photograph the oscilloscope display with the Polaroid camera and record the following information

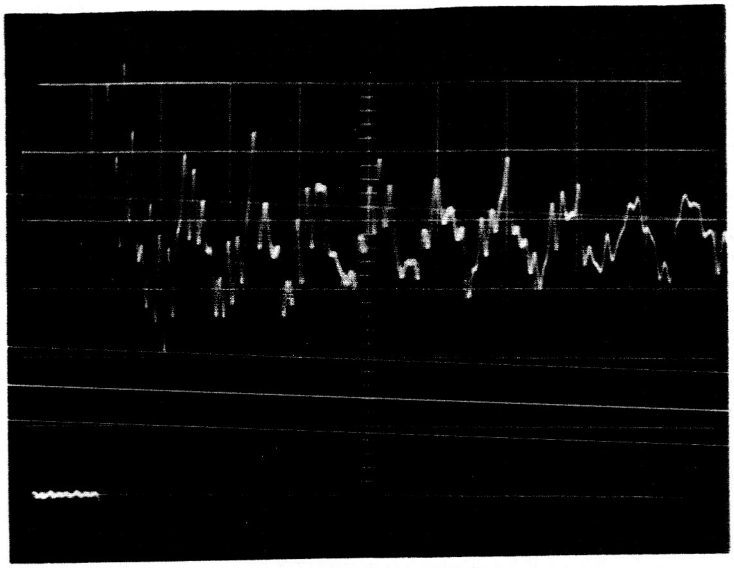
Date	Time	Picture No.	Vert. Sens.	Horiz. Sens.	Test Section Pressure psia	Burst Pressure psia	
6-29-65		1	555 mv/cm	50 μs/cm	6.3	547	(No Bleed)
"		2	"	"	"	545	(Bleed)
"		3	"	10 μs/cm	"	530	(No Bleed)
"		4	"	"	"	537	(Bleed)

e. Insert ¼ inch thick steel plate between tube flanges ahead of transducer and repeat item d.

Date	Time	Picture No.	Vert. Sens.	Horiz. Sens.	Test Section Pressure psia	Burst Pressure psia	
6-29-65		5	555 mv/cm	10 μs/cm	6.3	537	(Blank)
"		6	"	50 μs/cm	"	"	(Blank)

Other Data:

Dynamic Tests in Shock Tube



Picture No. 1

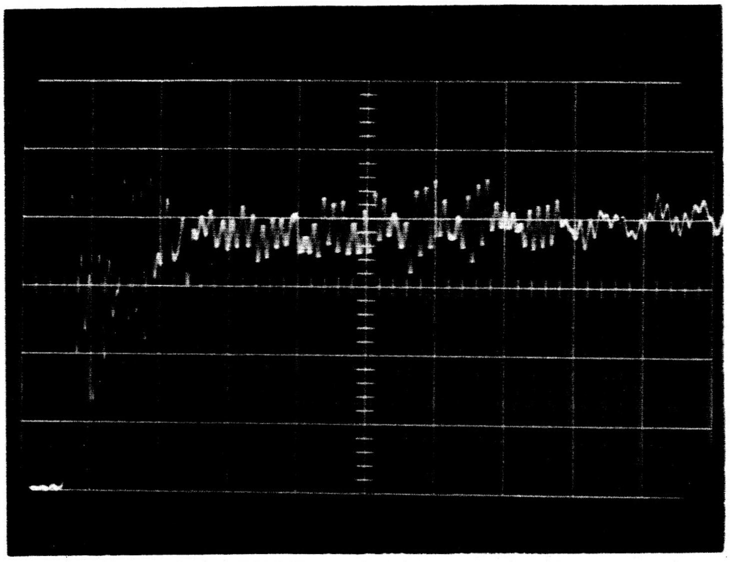
Vert. Sens. 555 mv/cm

Sweep Rate 50 μs/cm

Rise Time

Nat'l Freq. ±22,250

(No Helium Bleed)



Picture No. 2

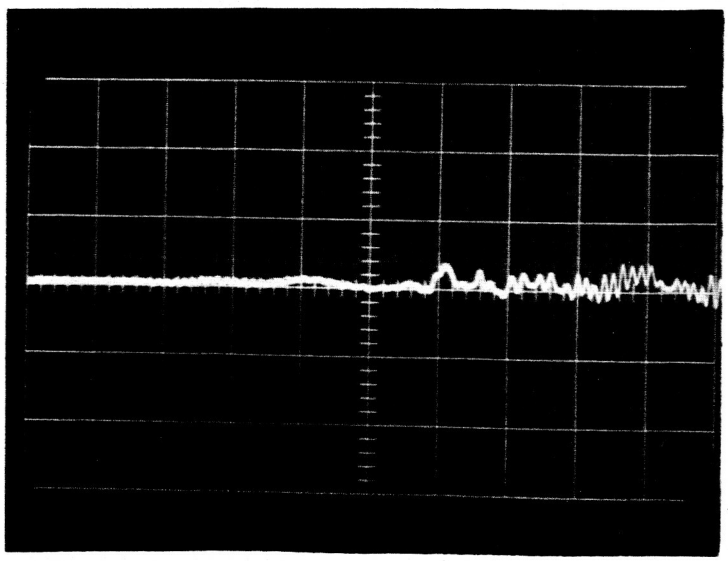
Vert. Sens. 555 mV/cm

Sweep Rate 50 μs/cm

Rise Time

Nat'l Freq.

(Helium Bleed)



Picture No. 6

Vert. Sens. 555 mv/cm

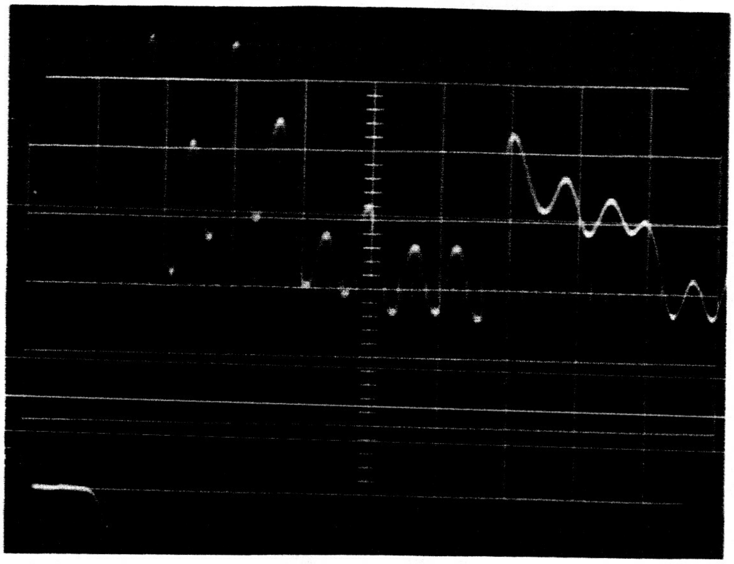
Sweep Rate 50 μs/cm

Rise Time

Nat'l Freq.

(Blank Shot)

Dynamic Tests in Shock Tube



Picture No. 3

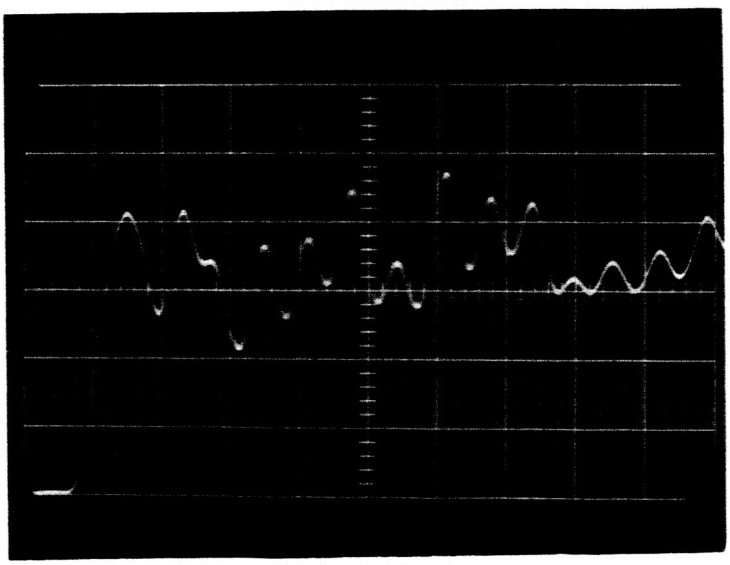
Vert. Sens. 555 mv/cm

Sweep Rate 10 μs/cm

Rise Time

Nat'l Freq.

(No Helium Bleed)



Picture No. 4

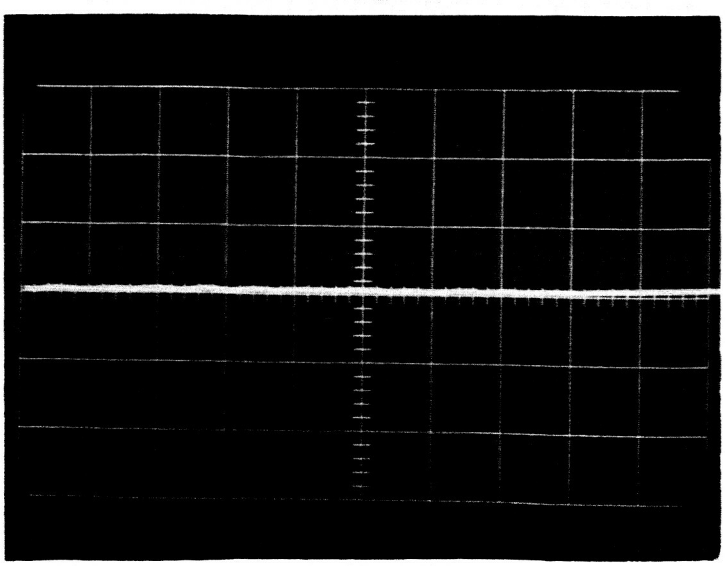
Vert. Sens. 555 mv/cm

Sweep Rate 10 μs/cm

Rise Time

Nat'l Freq.

(Helium Blead)



Picture No. 5

Vert. Sens. 555 mv/cm

Sweep Rate 10 μs/cm

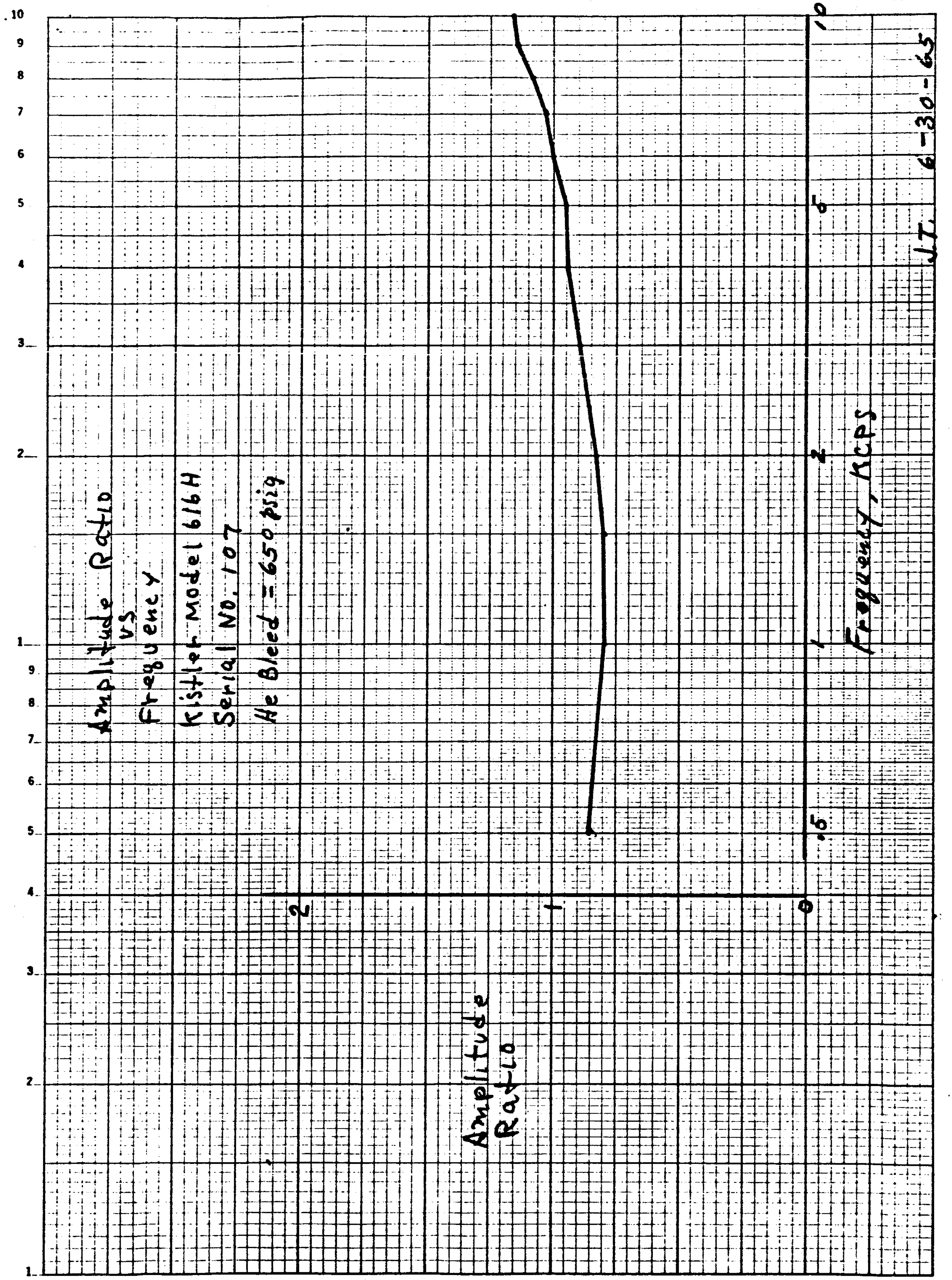
Rise Time

Nat'l Freq.

(Blank Shot)

D. Dynamic Testing (cont'd)	Initial Time Date
3. Sinusoidal Pressure Generator a. Install the transducer in the generator chamber. Establish coolant flow and allow adequate warm up time. Plenim Pressure 1030 psig Chamber Pressure 250 psig Test Gas Helium Diaphragm Position Flush	6-30-65 J.T.
b. At 1000 cps, check peak to peak chamber pressure from output of monitor transducer and average chamber pressure from both test and monitor transducers. P_c, test 250 psig P_c, Mon. 250 psig pk-pk 82 psig	6-30-65 J.T.
c. At each excitation frequency record output level for each channel as indicated n the volt meter.	6-30-65 J.T.

Frequency (kcps)	Monitor Output mv	Test Output mv
0.5	6900	5900
1.0	5800	4600
1.5	4400	3600
2	3450	2900
3	2420	2150
4	1870	1760
5	1550	1470
6	1275	1275
7	1100	1130
8	960	1040
9	850	970
10	750	870


Amplitude Ratio
vs
Frequency
Kistler Model 616H
Serial No. 107
He Bleed = 650 psig
Frequency, KCPS
Amplitude Ratio
J.T. 6-30-65
.5
1
2
5
10
0
1
2

PRINCETON UNIVERSITY
DEPARTMENT OF AEROSPACE AND MECHANICAL SCIENCES
GUGGENHEIM LABORATORIES FOR THE AEROSPACE PROPULSION SCIENCES

FORM NO. 93e

JP-24 LABORATORY EVALUATION PROCEDURE FOR CURRENT WATER-COOLED FLUSH DIAPHRAGM

TRANSIENT PRESSURE TRANSDUCERS

Type of Transducer: Piezoelectric Quartz Crystal

Manufacturer: Kistler Instr. Corp. Model: 616A Serial: 5163

Other Data:

Requested by: Conducted by: J. T., F. S.

Approved by: J.T.

Date Start: 1 Jan. 1965 Date Stop: 27 Jan. 1965

A. Inspection	Initial Time Date
1. Inspect transducer, especially for flaws or damage with a stereo-microscope and Zyglo as necessary, noting cracks, dents, imperfect welds, etc. (Attached photos or sketches as required). Adapter full of oil.	J.T. 1-14-65
2. Measure transducer for compliance with outline drawing. Note deviations: Within tolerance.	J.T. 1-14-65
3. Measure leakage resistance from all active pins to ground using the volt-ohmyst. Leakage resistance = megohm. 150 volt charge decayed to 142 volts in 5 min.	F.S. 1-14-65
4. For strain gage type transducers, measure resistances using the Wheatstone bridge. Input resistance = ______ ohms. Output resistance = ______ ohms.	DNA

B. Coolant Testing	Initial Time Date
1. Install transducer in static test system in accordance with instructions dated 2 June '64 for coolant flow tests and static pressure calibrations. Use Δp- ΔT fittings, coolant inlet filter, coolant outlet sight-glass, and selected gaskets.	J.T. 1-18-65

N.B. These fittings are to remain on transducer throughout the evaluation. Connect transducer to instruments and auxiliary equipment. Follow manufacturer's procedures for the adjustment of auxiliary equipment and allow recommended warm-up time.

Transducer gasket Flexitallic Adapter gasket Flexitallic

Δp- ΔT Set No. 12 Max. Torque 100 in. lb.

Torque, in. lb.	0	100							
Output, mv	.04	.04							

Auxiliary equipment, Serial No(s) and control settings

504 Chg. Amp. S/N 202

200.4:1 Voltage Divider

2. Attach coolant and instrumentation lines for coolant flow rate vs pressure drop test at rated average coolant pressure of 1000 psig.

Flow Meter Serial No. PU 3/16-5. Flow Meter Constant 1031 cycles/lb

J.T. 1-18-65

P_{in} psig	P_{out} psig	ΔP $P_{in}-P_{out}$	Coolant cps	Flow pps	Transducer Output mv	Transducer Output psig	Coolant Temperature mv	Coolant Temperature °F	
0	0	0	0	0					
1100	900	200	256	.2480	0.64	0	.65	62	(Coolant noise)
0	0	0	0	0	0.64	"	"	"	
1050	950	100	184	.1785	0.64	"	"	"	
0	0	0	0	0	0.64	0	.65	"	(Transfer H_2O
0	0	0	0	0	0.72	0	.60	60	
1025	975	50	130	.1260	0.72	0	"	"	
0	0	0	0	0					

Note: No apparent change in coolant flow on reverse flow check

B. Coolant Testing

5. Repeat item 3.

P_{in} psig	P_{out} psig	ΔP $P_{in}-P_{out}$	Coolant cps	Flow pps	Transducer Output mv	Transducer Output psig	Coolant Temperature mv	Coolant Temperature °F
0	0	0	0	0				
0	0	0	0	0				

6. Disconnect signal lead and repeat item A3. Leakage resistance ____________________.

7. Connect signal lead and leave transducer energized. Report coolant test data.

8. Tag transducer for coolant conditions as follows:
   a. Inlet Pressure 1025 psig.
   b. Outlet Pressure 975 psig.
   c. Average Coolant Pressure 1000 psig.
   d. Coolant Flowrate .126 lb./sec.
   e. Inlet tube as determined by items B2 and B4.

   N.B. All testing unless specifically directed otherwise, is to be carried out under the above conditions until the transducer is re-evaluated.

9. With coolant flowing observe zero reading during a one hour period at 5-minute intervals. Report any significant shift in zero. Voltage Divider 202.4:1

1-18-65
F.C.d.

Time of day	Output mv	Time of day	Output mv	Time of day	Output mv
3:25	-1.37	3:45	-1.52	4:05	-1.67
	-1.40		-1.56		-1.69
	-1.42		-1.60		-1.71
	-1.48		-1.63		-1.74
					-1.77

Drift ≈ .27 psi/min

C. Static Testing	Initial Time and Date
1. ~~Completely purge coolant passages of water with dry nitrogen gas from static test panel at 20 psig max. Leave coolant lines disconnected.~~	DNA
2. Apply 2000 psig to transducer. Insert on appropriate voltage divider to bring output on the calibrator scale. Divider ratio = 200.4 . Release applied pressure.	7.E.I. 1-18-65
3. Apply pressure in 100 psi steps to 2000 psig and return in equal steps to zero pressure. N. B. Care must be taken to approach each pressure in the particular direction of travel to avoid any masking of hysteresis or other effects. Computing identification 1631 .	7.E.I. 1-18-65

Ascending Pressure Output (mv)	Applied Pressure (psig)	Descending Pressure output (mv)
.15 .04	0	-.17 -.08
2.61	100	2.26
5.06	200	4.66
7.52 7.43	300	7.15 7.21
9.91	400	9.59
12.33	500	12.03
14.83 14.73	600	14.46 14.53
17.24	700	16.96
19.68	800	19.42
22.18 22.10	900	21.96 21.94
24.62	1000	24.43
27.14	1100	26.91
29.59 29.56	1200	29.40 29.41
32.10	1300	31.92
34.60	1400	34.36
37.04 37.05	1500	36.88 36.88
39.55	1600	39.43
42.02	1700	41.92
44.52 44.47	1800	44.40 44.41
47.01	1900	46.92
49.51 49.49	2000	49.51 49.49

↓ Ascending Pressure   Descending Pressure ↑

NO. PTS.	ID	SLOPE	Volts / psi	Y-INTERCEPT	AVE. DEV.
42	1631	.49561935E-02		-.14670686E-01	.71180521E-0[illegible]

C. Static Testing (cont'd)			Initial Time and Date
4. Establish rated coolant flow and repeat Item C3. **Make certain** that zero pressure output has stablized before proceeding. Seat transducer diaphragm. Computing identification 1632.			RE 8. 1-18-65
Ascending Output Voltage (mV)	Applied Pressure (psig)	Descending Output Voltage (mV)	
0.71	0	0.70	
1.70	100	1.53	
4.15	200	3.92	
6.63	300	6.40	
9.06	400	8.85	
11.52	500	11.28	
13.95	600	13.76	
16.39	700	16.24	
18.87	800	18.68	
21.33	900	21.17	
23.82	1000	23.62	
26.26	1100	26.15	
28.80	1200	28.66	
31.21	1300	31.16	
33.72	1400	33.64	
36.23	1500	36.14	
38.72	1600	38.65	
41.20	1700	41.18	
43.71	1800	43.65	
46.21	1900	46.18	
47.38	1947	47.38	

Ascending Pressure ↓   Descending Pressure ↑

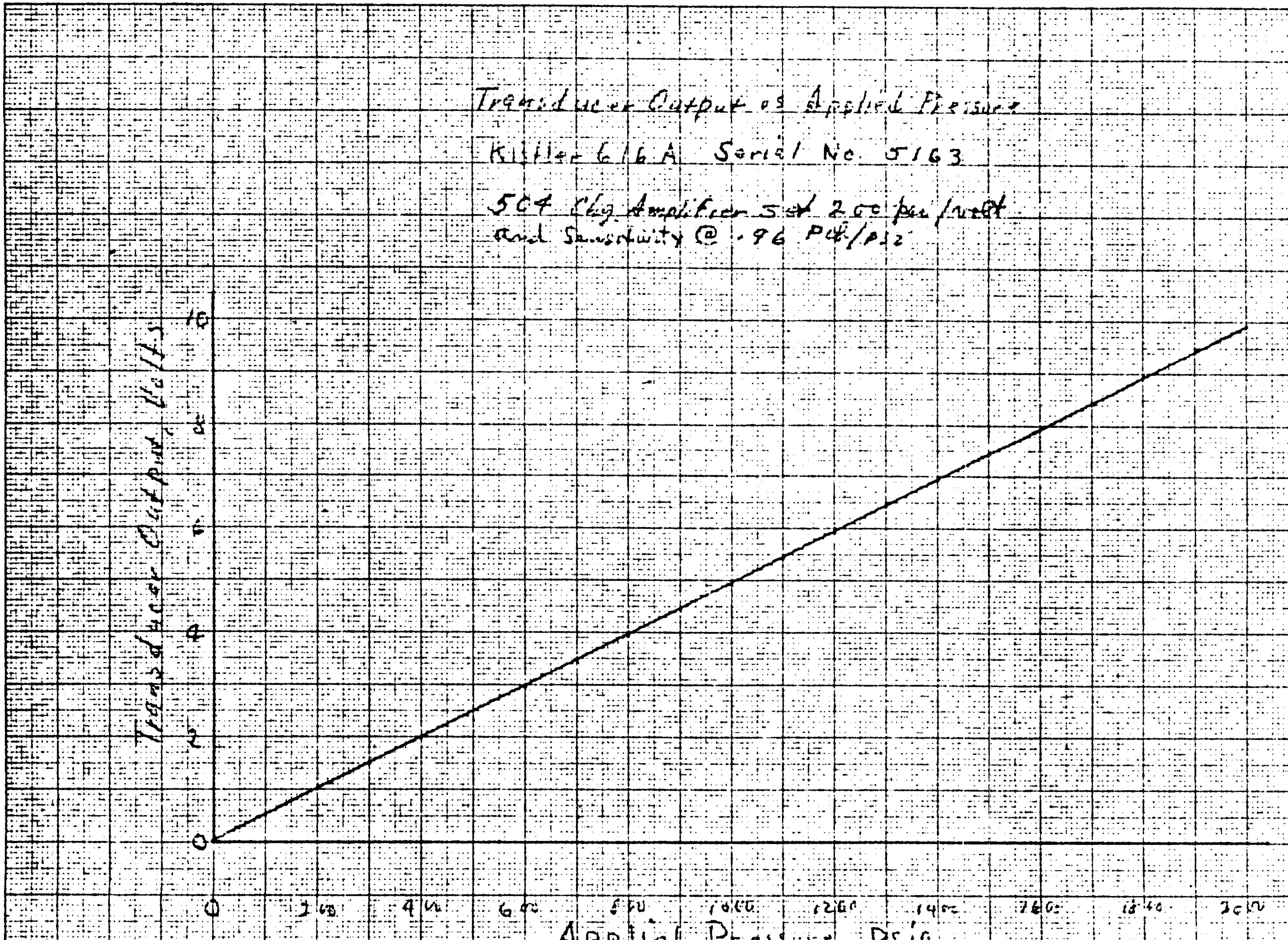
NO.PTS.	ID	SLOPE Volts/psi	Y-INTERCEPT	AVE. DEV.
42	1632	.49224214E-02	-.13378503E+00	.73678839E-01

C. Static Testing (cont'd)			Initial Time and Date
5. Duplicate Item C4 to determine repeatability. Seat transducer diaphragm. Computing identification 1633.			F.S.H. 1-18-65
~~Ascending~~ Descending Output Voltage (mv)	Applied Pressure (psig)	~~Descending~~ Ascending Output Voltage (mV)	
47.94	1990 / 1971	47.37	
45.61	1900	45.60	
43.13	1800	43.08	
40.67	1700	40.61	
38.12	1600	38.11	
35.62	1500	35.60	
33.16	1400	33.11	
30.67	1300	30.64	
28.18	1200	28.19	
25.64	1100	25.63	
23.21	1000	23.18	
20.75	900	20.72	
18.24	800	18.23	
15.77	700	15.80	
13.32	600	13.32	
10.85	500	10.90	
8.40	400	8.43	
5.98	300	6.01	
3.57	200	3.52	
1.07	100	1.12	
-1.33	0	-1.33	

~~Ascending~~ Descending Pressure ↓   ~~Descending~~ Ascending Pressure ↑

Note: Calibration range 2000 psi to 0 psi & return.

NO.PTS.	ID	SLOPE Volts/psi	Y-INTERCEPT	AVE. DEV.
42	6133	.48973649E-02	-.20869939E+00	.10296785E+00


Transducer Output vs Applied Pressure
Kistler 616 A Serial No. 5163
504 Chg Amplifier set 200 pC/volt
And Sensitivity @ .96 PC/PSI
Transducer Output, Volts
0
2
4
6
8
10
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Applied Pressure, psig

D. Dynamic Testing (cont'd)	Initial Time and Date
2. Shock Tube Testing a. Install the transducer in accordance with instructions dated 2 June 1964 for coolant flow and static testing. Transducer Location End Diaphragm Position Flush	1-18-65 FD
b. Establish coolant flow through the transducer and allow adequate warm-up time.	1-18-65
c. Insert a burst disc in the shock tube and proceed according to instructions dated 5 June 1964. Test Gas N_2 Test Pressure 6.2 psia Driver Gas He Burst Disk size 540 psi	1-18-65 FD
d. Photograph the oscilloscope display with the Polaroid camera and record the following information	1-20-65 FD

Date	Time	Picture No.	Vert. Sens.	Horiz. Sens.	Test Section Pressure psia	Burst Pressure psia
1-20-65	3:30		500mv/cm	20µs/cm	6.2	520
1-20-65	3:45		500mv/cm	10µs/cm	6.2	520

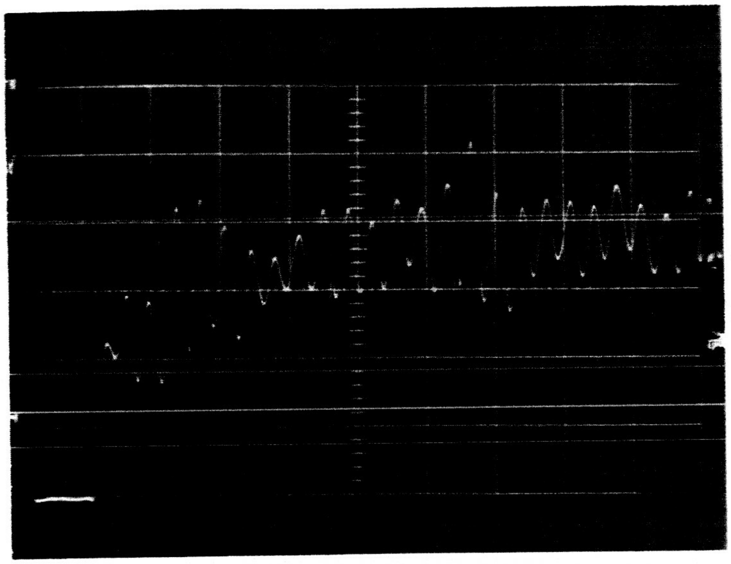
e. Insert ½ inch thick steel plate between tube flanges ahead of transducer and repeat item d. — 1-20-65 FD

Date	Time	Picture No.	Vert. Sens.	Horiz. Sens.	Test Section Pressure psia	Burst Pressure psia
1-20-65	4:00		500mv/cm	20µs/cm	6.2	530
1-20-65	4:15		500mv/cm	10µs/cm	6.2	532

Other Data:

12 photos taken in effort to duplicate data.
Transducer assembly recleaned in ultrasonic cleaner with Freon prior to these shots.
Difficult to determine rise time from data.

Dynamic Tests in Shock Tube



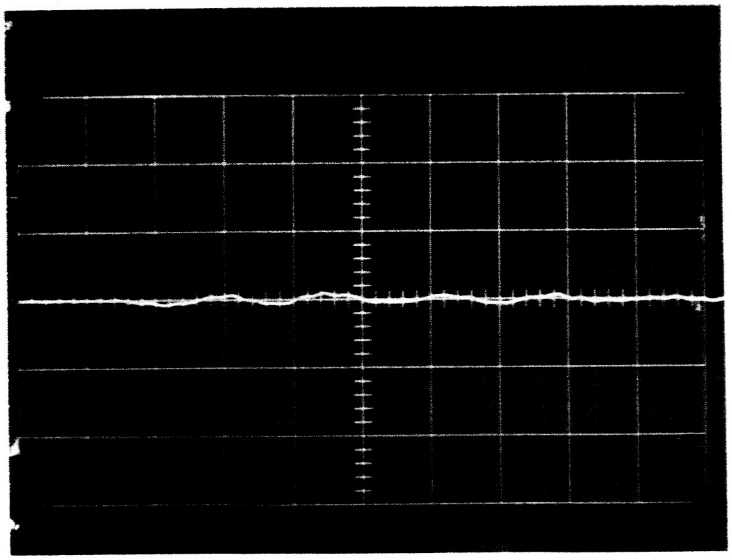
Picture No. 1

Vert. Sens. 500 mv/cm

Sweep Rate 20 μs/cm

Rise Time

Nat'l Freq.



Picture No. 3

Vert. Sens. 500 mV/cm

Sweep Rate 20 μs/cm

Rise Time

Nat'l Freq.

Picture No.

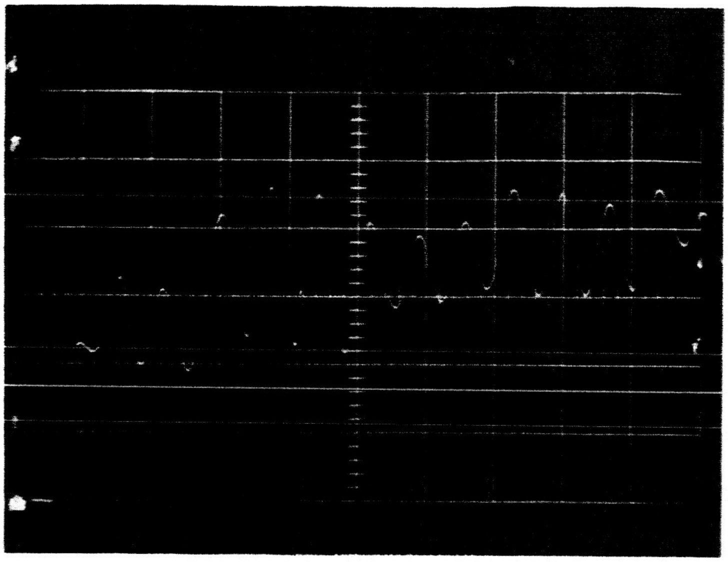
Vert. Sens.

Sweep Rate

Rise Time

Nat'l Freq.

Dynamic Tests in Shock Tube



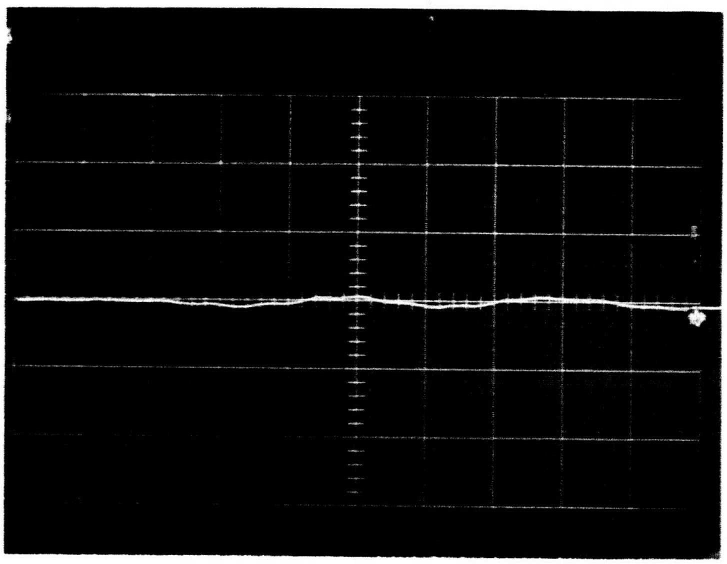
Picture No. 2

Vert. Sens. 500 mv/cm

Sweep Rate 10 μs/cm

Rise Time ____________

Nat'l Freq. ____________



Picture No. 4

Vert. Sens. 500 mv/cm

Sweep Rate 10 μs/cm

Rise Time ____________

Nat'l Freq. ____________

Picture No. ____________

Vert. Sens. ____________

Sweep Rate ____________

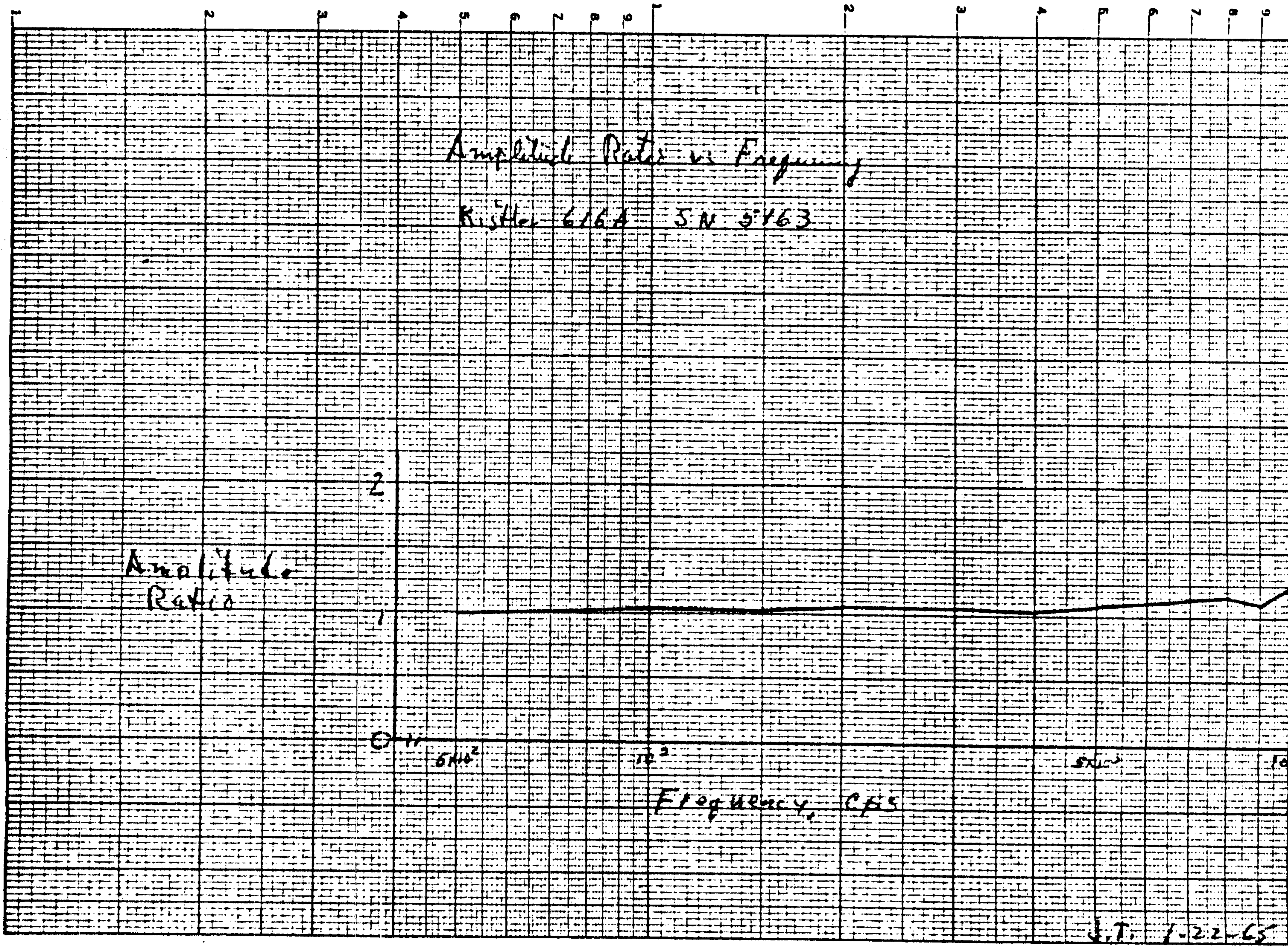
Rise Time ____________

Nat'l Freq. ____________

D. Dynamic Testing (cont'd)	Initial Time Date
3. Sinusoidal Pressure Generator a. Install the transducer in the generator chamber. Establish coolant flow and allow adequate warm up time. Plenim Pressure 1030 psig Chamber Pressure 250 psig Test Gas Helium Diaphragm Position Adapter Flush	J.E.S. 1-22-65
b. At 1000 cps, check peak to peak chamber pressure from output of monitor transducer. and average chamber pressure from both test and monitor transducers. P_c, test 250 psig P_c, Mon. 250 psig pk-pk ≅57 psig	
c. At each excitation frequency record output level for each channel as indicated on the volt meter.	

Chg. amp setting	Frequency (kcps)	Monitor Output mv	Test Output mv	504 Charge amp setting
	0.5	4600	3950	
10 mv/pch	1.0	3100	2800	100 psi/volt
	1.5	2190	1970	
20 mv/pch	2	3300	3050	50 psi/volt
	3	2300	2125	
	4	4200	3725	
50 mv/pch	5	3400	3175	20 psi/volt
	6	2925	2800	
	7	2600	2575	
	8	2350	2375	
	9	2175	2250	
	10	1950	2125	
[Moni]tor Sensitivity 1.11 pcb/psi				(Sensitivity = .96 pcb/psi

Sensitivity from computing = 4.93 mv/psi
= 9.86 volts F.S. @ 2000 psi.


Amplitude Ratio vs Frequency
Kistler 616A SN 5763
Amplitude Ratio
2
1
0
5x10²
10²
5x10³
10⁴
Frequency, cps
J.T. 1-22-65

E. Heat Transfer Testing	Initial Time and Date
1. Open Flame Test a. Install transducer in test apparatus and proceed according to instructions dated Diaphragm position Adapter Flush .	1-27-65 FB.
b. Check coolant supply level.	1-27-65 FB.
c. Ice cold junctions and check instrumentation.	1-27-65 FB.
d. Establish coolant flow and allow adequate warm-up time.	
e. Prescribed operation conditions: Δ T instrument range ±4 mv. Transducer body temp. ±1.5 mv. Transducer position, D 3/4" in. Approximate heat flux 1.5 BTU/in^{2}sec Ox gas 28 CFH, 40 psig Fuel gas 26 CFH 10 psig	
f. Get data points 1 and 2 below. Ignite torch and complete test. N. B. Hold coolant pressure throughout test.	

Data Point	Coolant Flow cps	Coolant T_{in} mv	Transducer Output mv	Transducer Output psi	
1 Coolant off	.0	.65	0		
2 Coolant on	141	.65	0		Coolant leak at base of outlet tube on start up
3 Heat on	"	"	-.23	-9.5 psi	
4 Both off	0	"	0		

Note: Attach ΔT trace to this form

$\dot{w} = .137$ #/sec

$\Delta t = 2.8\,°F$

$A = .15\ in^2$

$q = \frac{.137(2.8)}{.15} = 2.56$ Btu/in^2 sec.

PRINCETON UNIVERSITY
Department of Aerospace and Mechanical Sciences
Guggenheim Laboratories for the Aerospace Propulsion Sciences

FORM NO. 93e

JP-24 LABORATORY EVALUATION PROCEDURE FOR CURRENT WATER-COOLED FLUSH DIAPHRAGM TRANSIENT PRESSURE TRANSDUCERS

Type of Transducer: Semiconductor Strain Gage

Manufacturer: Photocon Research Prod. Model: PRP 200 Serial: 107

Other Data:

Requested by: Conducted by: F.E.S., J.P.T.

Approved by: J.P.T.

Date Start: 6-21-65 Date Stop: 6-29-65

A. Inspection	Initial Time Date
1. Inspect transducer, especially for flaws or damage with a stereo-microscope and Zyglo as necessary, noting cracks, dents, imperfect welds, etc. (Attached photos or sketches as required).	J.T. 6-21-65
2. Measure transducer for compliance with outline drawing. Note deviations: None	J.T. 6-21
3. Measure leakage resistance from all active pins to ground using the volt-ohmyst. Leakage resistance = ∞ megohm.	J.T. 6-21
4. For strain gage type transducers, measure resistances using the Wheatstone bridge Input resistance = 338.6 ohms. Output resistance = 338.7 ohms.	F.E.S. 6-21

C. Static Testing

Initial Time

NO. PTS.	ID	SLOPE	Y-INTERCEPT	AVE. DEV.
42	2001	.46274490E-01	.37765429E+02	.73244631E+01

2. Apply 2000 psig to transducer. Insert on appropriate voltage divider to bring output on the calibrator scale. Divider ratio = ———. Release applied pressure. — 6-23 JS

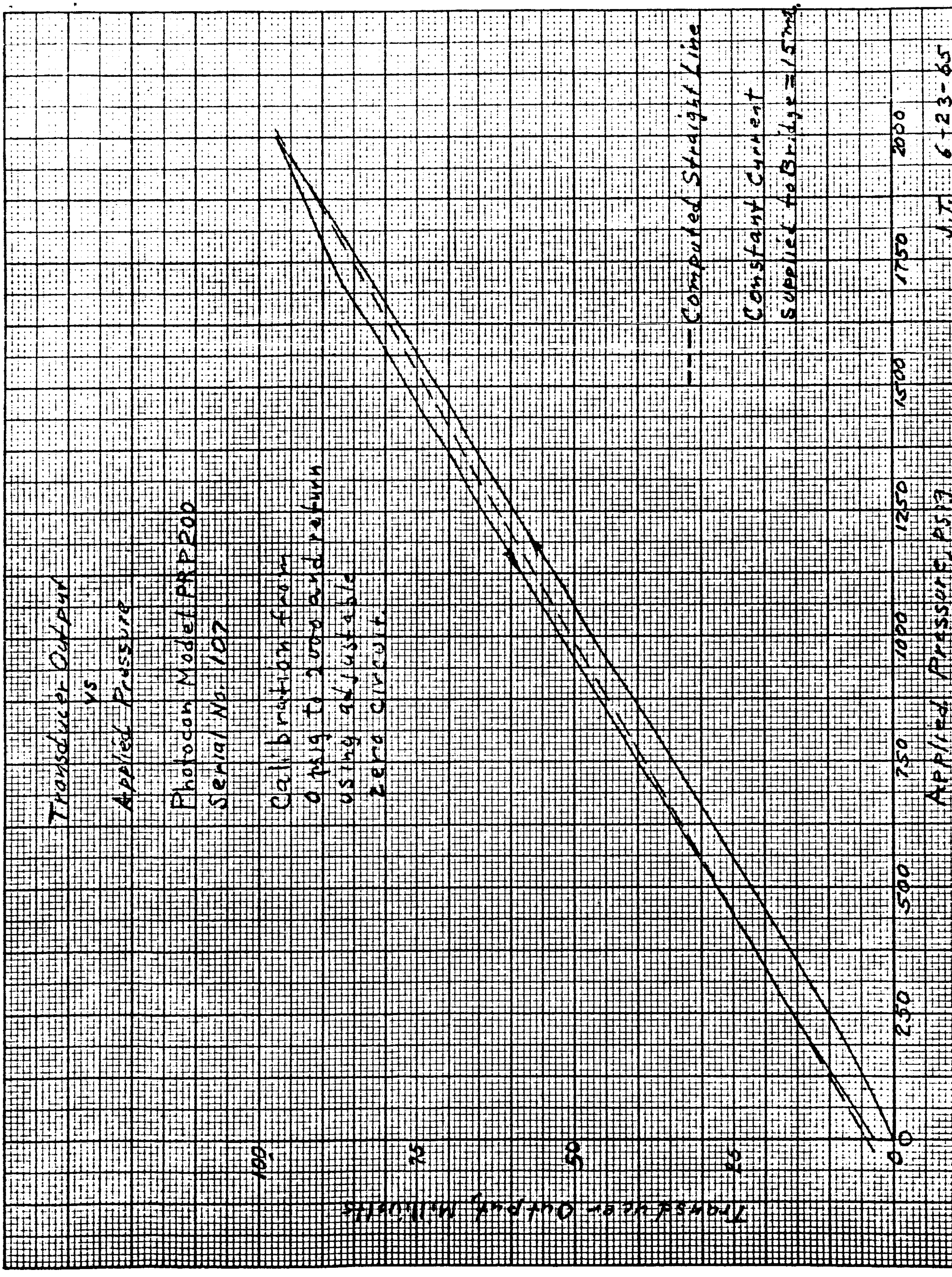
3. Apply pressure in 100 psi steps to 2000 psig and return in equal steps to zero pressure.
   N. B. Care must be taken to approach each pressure in the particular direction of travel to avoid any masking of hysteresis or other effects.
   Computing identification 2001.

Ascending Pressure Output (mv)	Applied Pressure (psig)	Descending Pressure output (mv)
-41.95	0	-38.47
-38.36	100	-37.40
-33.90	200	-28.86
-29.34	300	-24.00
-24.48	400	-19.10
-19.74	500	-14.23
-14.98	600	-9.46
-9.86	700	-4.55
-5.08	800	+0.48
-0.07	900	5.28
+5.38	1000	10.20
9.88	1100	15.08
14.96	1200	20.00
20.00	1300	24.92
25.07	1400	29.62
30.00	1500	34.62
34.98	1600	39.42
39.98	1700	44.80
44.80	1800	48.40
49.90	1900	51.90
55.16	2000	55.16

Ascending Pressure — Descending Pressure

N.B. Report apparent erroneous data before proceeding with evaluation.

Constant Current @ 15 milliamps
Kepco Power Supply Model CK 36-1.5 S/N 40465
Simpson Model 29 D-C Milliammeter S/N 6893


Transducer Output
vs
Applied Pressure
Photocon Model PRP200
Serial No. 107
Calibration from
0 psig to 2000 and return
using adjustable
zero circuit.
--- Computed Straight Line
Constant Current
Supplied to Bridge = 15 ma.
J.T. 6-23-65
0
250
500
750
1000
1250
1500
1750
2000
Applied Pressure, PSIG
0
25
50
75
100
Transducer Output, Millivolts

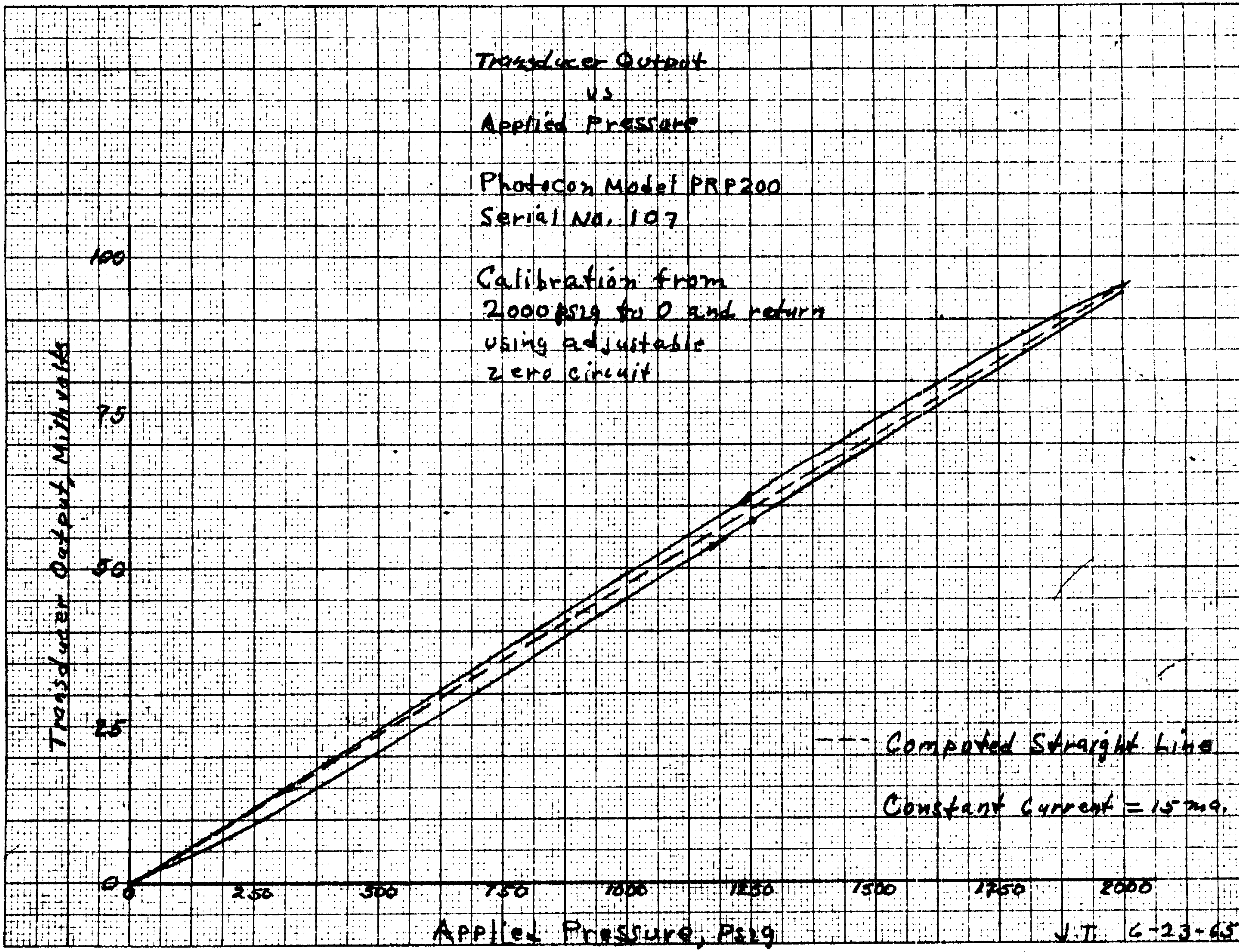
C. Static Testing (cont'd)	Initial Time and Date
4. Establish rated coolant flow and repeat Item C3. **Make certain** that zero pressure output has stablized before proceeding. Seat transducer diaphragm. Computing identification 2002.	J.T. 6-23-65

Ascending Output Voltage (mV)	Applied Pressure (psig)	Descending Output Voltage (mV)
− 38.20	0	− 38.20
− 24.43	200	− 31.20
− 18.58	400	− 22.06
− 3.60	700	− 7.64
+ 11.02	1000	+ 2.00
+ 25.85	1300	21.88
+ 40.55	1600	36.80
49.82	~~18~~ 1800	46.65
57.36	2000	56.00

Ascending Pressure ↓ — Descending Pressure ↑

Calibration from 2000 psig to zero & return.

NO. PTS.	10	SLOPE	Y-INTERCEPT	AVE. DEV.
ID	2002	.46220693E-01	-.39052917E+02	.16[illegible]0871E+01


Transducer Output
vs
Applied Pressure
Photocon Model PRP200
Serial No. 107
Calibration from
2000 psig to 0 and return
using adjustable
zero circuit
Transducer Output, Millivolts
100
75
50
25
0
0
250
500
750
1000
1250
1500
1750
2000
Applied Pressure, Psig
--- Computed Straight Line
Constant Current = 15 ma.
J.T. 6-23-65

C. Static Testing (cont'd)

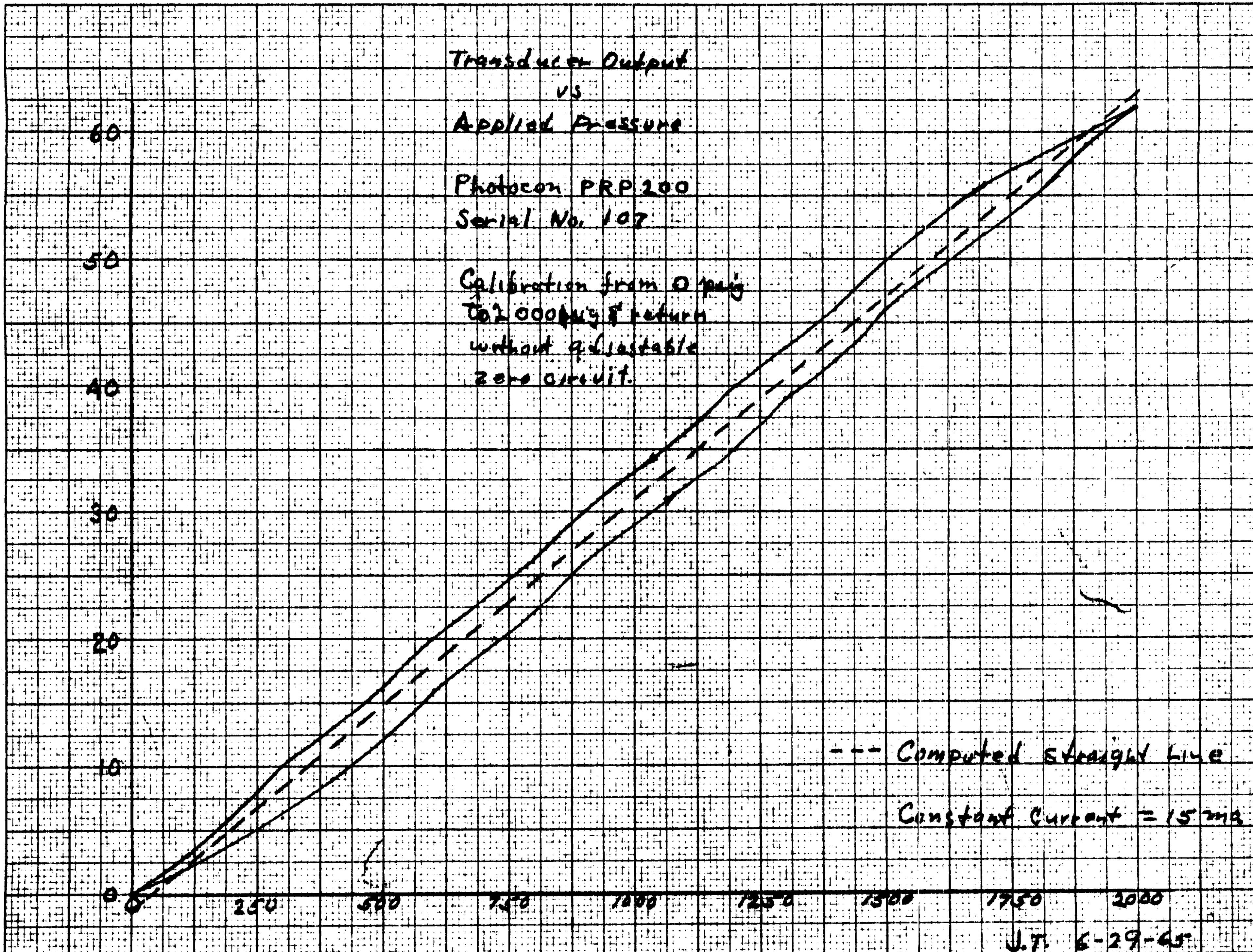
	Initial Time and Date
5. Duplicate Item C4 to determine repeatability. Seat transducer diaphragm. Computing Identification 2003.	J.T. 6-29-65

Ascending Output Voltage (Volts)	Applied Pressure (psig)	Descending Output Voltage (Volts)
.066	0	.066
.068	100	.069
.070	200	.072
.072	300	.076
.075	400	.079
.078	500	.082
.082	600	.086
.085	700	.089
.088	800	.092
.092	900	.096
.095	1000	.099
.098	1100	.102
.101	1200	.106
.105	1300	.109
.108	1400	.112
.112	1500	.116
.115	1600	.119
.118	1700	.122
.121	1800	.124
.125	1900	.126
.128	2000	.128

Ascending Pressure → ; ← Descending Pressure

Zero Adjust Circuit removed.
Readout on PAR Digital Voltmeter

O.PTS.	ID	SLOPE	Y-INTERCEPT	AVE. DEV.
42	2003	.32181818E-04	.64794372E-01	.18498391E-02


Transducer Output
vs
Applied Pressure
Photocon PRP 200
Serial No. 107
Calibration from 0 psig
To 2000 psig & return
without adjustable
zero circuit.
--- Computed Straight Line
Constant Current = 15 ma
0
10
20
30
40
50
60
250
500
750
1000
1250
1500
1750
2000
J.T. 6-29-65

D. Dynamic Testing (cont'd)	Initial Time and Date
2. Shock Tube Testing a. Install the transducer in accordance with instructions dated 2 June 1964 for coolant flow and static testing. Transducer Location End Diaphragm Position Flush	6/23/65 FES
b. Establish coolant flow through the transducer and allow adequate warm-up time.	
c. Insert a burst disc in the shock tube and proceed according to instructions dated 5 June 1964. Test Gas N_2 Test Pressure 6.3 psia Driver Gas He Burst Disk size 540 psi	

d. Photograph the oscilloscope display with the Polaroid camera and record the following information

Date	Time	Picture No.	Vert. Sens. mv/cm	Horiz. Sens. μs/cm	Test Section Pressure psia	Burst Pressure psia
6/23		1	3.5	50	6.3	545
		2	"	10	6.3	540
		5	"	50	6.3	545
		6	"	10	6.3	540

e. Insert ¼ inch thick steel plate between tube flanges ahead of transducer and repeat item d.

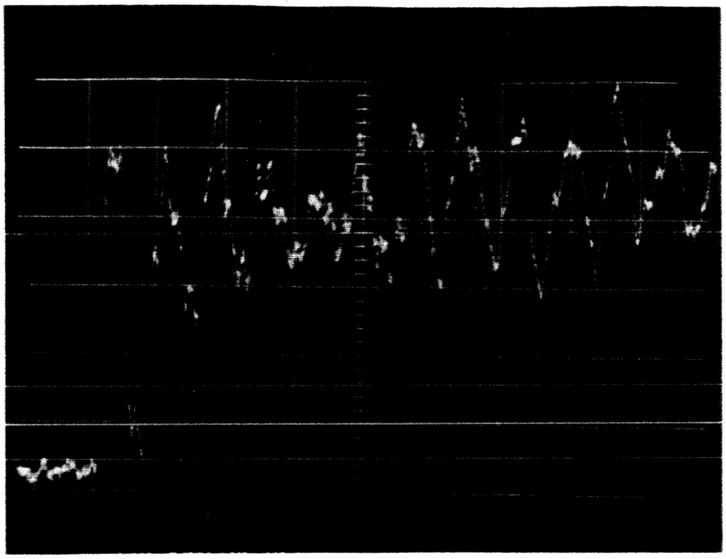
Date	Time	Picture No.	Vert. Sens.	Horiz. Sens.	Test Section Pressure psia	Burst Pressure psia
6/23		3	3.5	50	6.3	545
		4	"	10	6.3	545
		7	"	10	6.3	549

Other Data:

Shots 5, 6 and 7 made after disassembly, inspection and reassembly. Inspection made to double check concentricity – "o" ring lubrication and condition.

J.T.
6/23/65

Dynamic Tests in Shock Tube



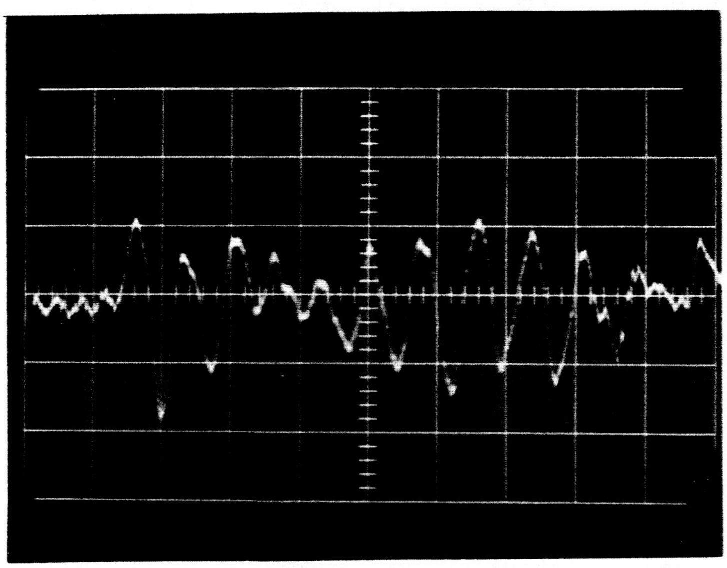
Picture No. 1

Vert. Sens. 3.5 mV/cm

Sweep Rate 50 μs/cm

Rise Time

Nat'l Freq. ≈ 26700



Picture No. 3

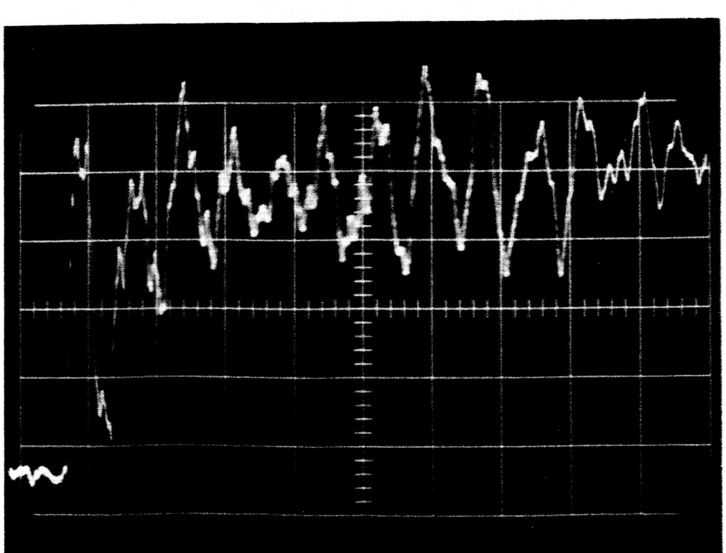
Vert. Sens. 3.5 mV/cm

Sweep Rate 50 μs/cm

Rise Time

Nat'l Freq. ≈ 26700

(Blanked off)



Picture No. 5

Vert. Sens. 3.5 mv/cm

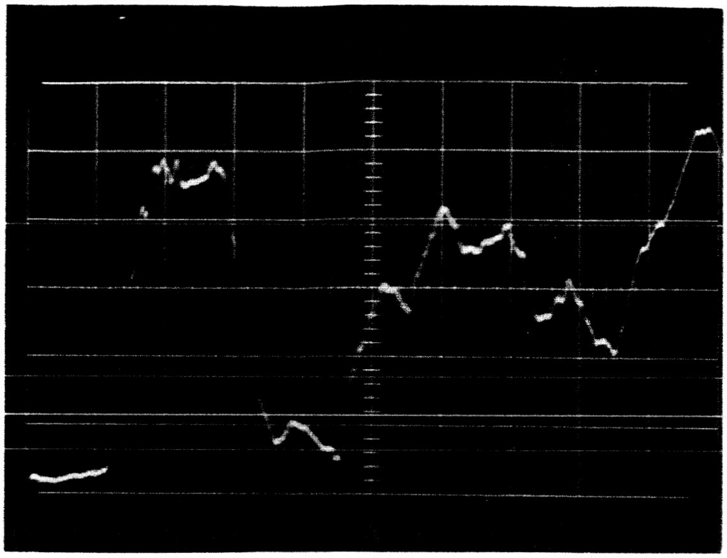
Sweep Rate 50 μs/cm

Rise Time

Nat'l Freq.

Shot made after adaptor assembly inspection and reassembly

Dynamic Tests in Shock Tube



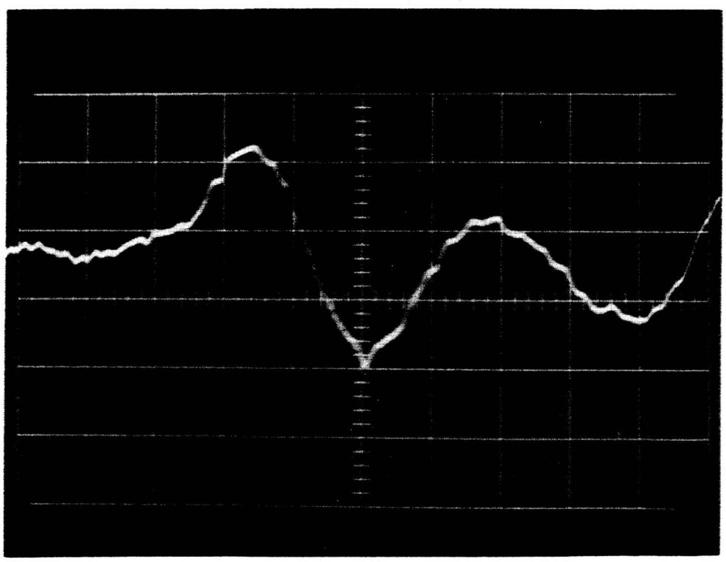
Picture No. 2

Vert. Sens. 3.5 mv/cm

Sweep Rate 10 μs/cm

Rise Time ____________

Nat'l Freq. ____________



Picture No. 4

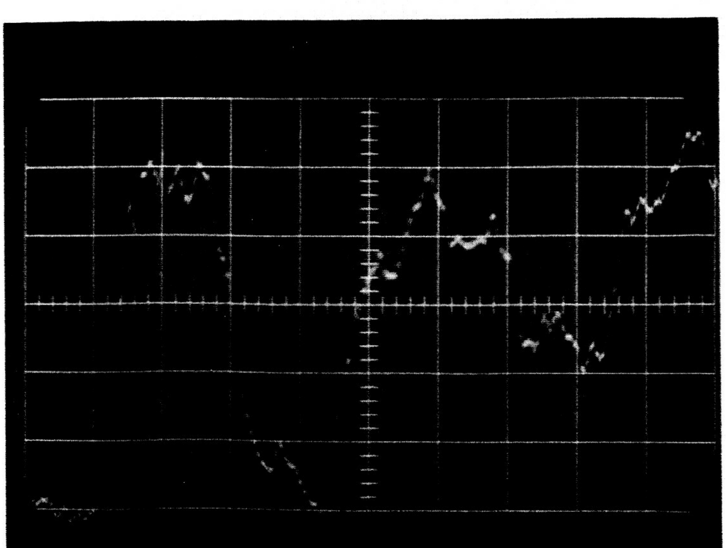
Vert. Sens. 3.5 mv/cm

Sweep Rate 10 μs/cm

Rise Time ____________

Nat'l Freq. ____________

(Blanked Off)



Picture No. 6

Vert. Sens. 3.5 mv/cm

Sweep Rate 10 μs/cm

Rise Time ____________

Nat'l Freq. ____________

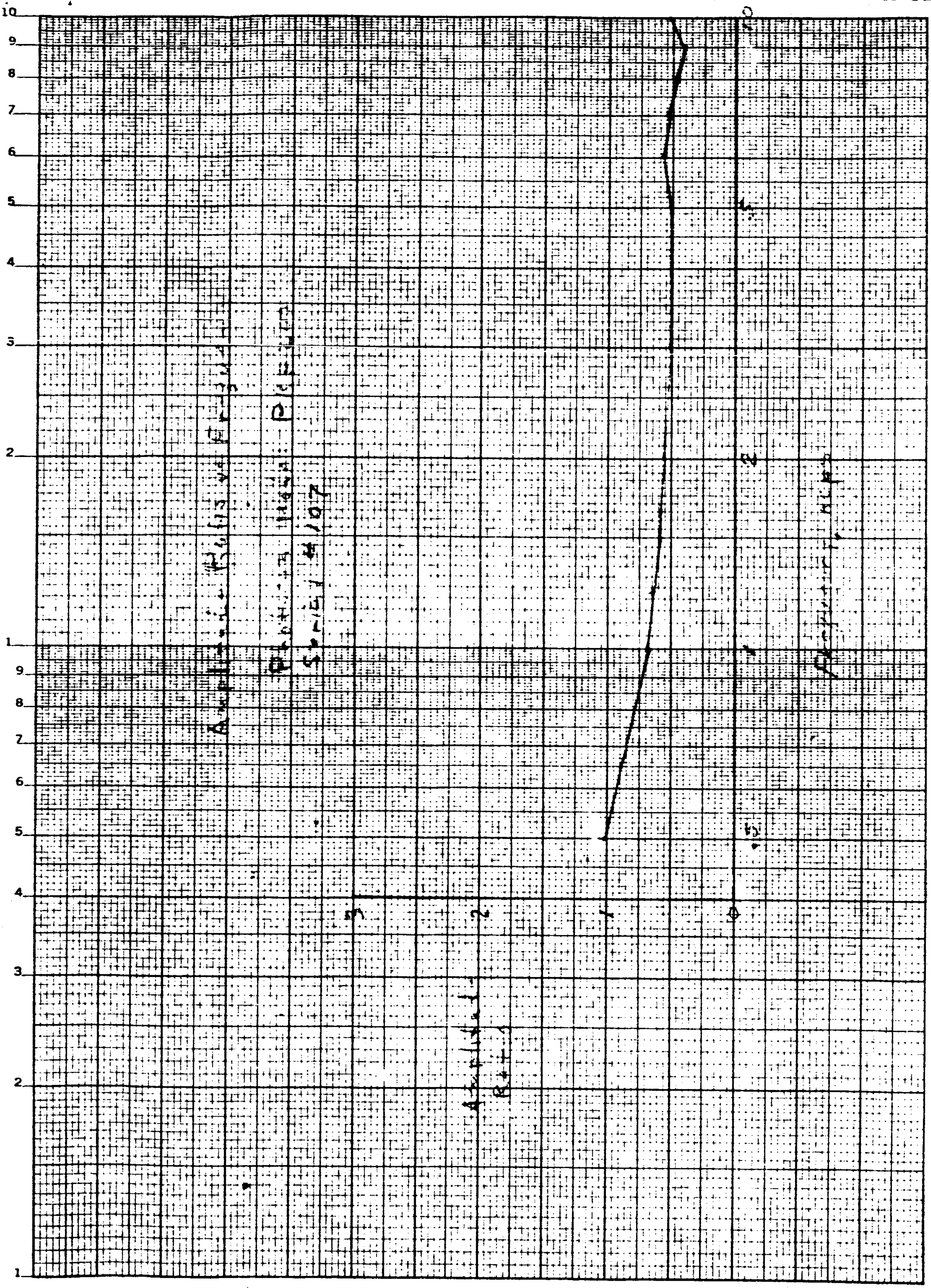
Shot made after inspection and reassembly

D. Dynamic Testing (cont'd)	Initial Time Date
3. Sinusoidal Pressure Generator a. Install the transducer in the generator chamber. Establish coolant flow and allow adequate warm up time. Plenim Pressure 1630 psig Chamber Pressure 250 psig Test Gas He. Diaphragm Position Flush	6-29-65 JT
b. At 1000 cps, check peak to peak chamber pressure from output of monitor transducer and average chamber pressure from both test and monitor transducers. P_c, test 250 psig P_c, Mon. 250 psig pk-pk 92 psig	
c. At each excitation frequency record output level for each channel as indicated on the volt meter.	

Frequency (kcps)	Monitor Output mv (rms)	Test Output mv (rms)
.5	7300	10750 1.032
1	6500	6200 .672
1.5	4900	4000 .573
2	3900	3100 .558
3	2780	2000 .506
4	2250	1340 .5[illegible]4
5	1720	1230 .5[illegible]25
6	1460	1220 .587
7	1280	1000 .549
8	1180	810 .483
9	1100	640 .409
10	1000	750 .527

Mon. Sens = 50 psi/volt
Mon. amp. = 10X
Test Sens = [illegible]002 mv/psi
Test amp = 950X

$R = 0.703 \left(\frac{T}{M}\right)$



APPENDIX B

Final List of Publications

on Transient Pressure Measuring Methods Research
under NASA Contracts NASr-36 and NAS8-11216

As of 30 June 1965

Jones, H. B., "Effects of Tubing Connection on Transducer Response," Princeton University Aeronautical Engineering Report No. 595a, January 1962.

Jones, H. B., "Transient Pressure Transducer Design and Evaluation," Princeton University Aeronautical Engineering Report No. 595b, February 1962.

Knauer, R. C., "Preliminary Evaluation of Available Transient Pressure Transducers for Rocket Motor Testing," Princeton University Aeronautical Engineering Report No. 595c, 28 May 1962 (Limited Distribution).

Carwile, C. L., "An Analytical and Experimental Study of the Response of a Small Chamber to Forced Pressure Oscillations," Princeton University Aeronautical Engineering Report No. 595d, 15 October 1962.

Layton, J. P., "Technical Note on a Small Passage Technique for Transient Chamber Pressure Measurements in Large Rocket Motors," Princeton University Aeronautical Engineering Report No. 595e, 31 October 1962 (Limited Distribution).

Layton, J. P., Knauer, R. C., and Thomas, J. P., "Summary Technical Report on Transient Pressure Measuring Methods Research, 1 March 1961 through 31 December 1962," Princeton University Aeronautical Engineering Report No. 595f, September 1963.

Bentley, W. C. and Walter, J. J., "Dynamic Response Testing of Transient Pressure Transducers for Liquid Propellant Rocket Combustion Chambers," Princeton University Aeronautical Engineering Report No. 595g, June 1963.

Knauer, R. C., "Technical Note on Response Testing of a Rocketdyne F-1 Thrust Chamber Pressure Measuring System," Princeton University Aeronaturical Engineering Report No. 595h, 12 June 1963 (Limited Distribution).

Layton, J. P., Knauer, R. C., and Thomas, J. P., "Summary Technical Report on Transient Pressure Measuring Methods Research, 1 January through 30 June 1963," Princeton University Aeronautical Engineering Report No. 595i, October 1963.

Knauer, R. C., "Technical Note on Response Testing of Kistler Adapters 628B and 628C, Princeton University Aeronautical Engineering Report No. 595j, 24 October 1963 (Limited Distribution).

Knauer, R. C., "Technical Note on Response Testing of Transducers Connected by Long Passages," Princeton University Aeronautical Engineering Report No. 595k, 31 October 1963 (Limited Distribution).

Knauer, R. C., "Technical Note on Response Tests of Two Cavity Type Pressure Transducers," Princeton University Aeronautical Engineering Report No. 595ℓ, 3 January 1965 (Limited Distribution).

Jones, H. B., Knauer, R. C., Layton, J. P., and Thomas, J. P., "Transient Pressure Measurements in Liquid Propellant Rocket Thrust Chambers," (Summary Technical Report through 31 December 1964, Princeton University Aeronautical Engineering Report No. 595m), ISA Transactions Volume 4, No. 2, April 1965.

Thomas, J. P., "Preliminary Technical Note on Evaluation of Electro-Optical Systems PT15C Series Silicon Semiconductor Strain Gage Bridge Transducers, Princeton University Aeronautical Engineering Report No. 595n, 22 December 1964 (Limited Distribution).

Michael, M. E., "Preliminary Technical Note on Evaluation of Aerojet-General Corporation Model HB3X Small Passage Technique," Princeton University Aeronautical Engineering Report No. 595o, 30 April 1965 (Limited Distribution).

Layton, J. P., and Thomas, J. P., "Summary Technical Report on Transient Pressure Measuring Methods Research, 1 January through 30 June 1965," Princeton University Aeronautical Engineering Report No. 595p, 16 November 1965.

Michael, M. E., "Dynamic Performance of Small Passage Connected Pressure Transducers," Princeton University Aeronautical Engineering Report No. 595q, (In Preparation).

Megerman, J., "Heat Transfer Measurements with Water Cooled Flush Diaphragm Pressure Transducers, Princeton University Aeronautical Engineering Report No. 595r, (In Preparation).

Obi, W. C., "Computer Analysis of the Transient Response of Pressure Transducers to Shock Inputs," Princeton University Aeronautical Engineering Report No. 595s, (In Preparation).

Layton, J. P. and Thomas, J. P., "Final Summary Technical Report on Transient Pressure Measuring Methods Research," Princeton University Aeronautical Engineering Report No. 595t, (In Preparation).

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